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TECHNICAL NOTE

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LOW-SPEED AERODYNAMIC CHARACTERISTICS OF A CANARD AIRPLANE CONFIGURATION HAVING SPLIT FLAPS LOCATED AHEAD OF THE WING TRAILING EDGE AND LEADING- AND TRAILING-EDGE FLAPS ON THE CANARD CONTROL

By Bernard Spencer, Jr.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

An investigation has been conducted at low subsonic speeds on the use of canard controls having leading- and trailing-edge flaps on an airplane configuration having a wing with a partial-span leading-edge chord-extension as a means of improving the control and maximum-lift characteristics of this type of configuration. Also investigated was the use of split flaps located at various wing-chord stations ahead of the trailing edge.

For a trapezoidal canard planform, higher values of control effectiveness at high angles of attack were obtained by using a trailing-edge flap than by deflecting the total canard surface. The magnitude of control effectiveness at low angles of attack, however, was considerably less for the canard trailing-edge flap than for the total canard surface. Comparison of the control effectiveness associated with a 60° canard planform and a trailing-edge flap located on this canard surface indicates a similar variation with angle of attack for both controls, although the magnitude of control effectiveness was lower for the canard trailing-edge flap control than for the case in which the total canard surface was deflected.

The use of a wing with a partial-span leading-edge chord-extension on a configuration having either the trapezoidal or the delta canard control indicated improvement in longitudinal stability at high lift coefficients and increased the maximum lift coefficient obtainable. Use of a wing split flap having its leading edge located along the 60-percent-chord line produced less resultant nose-down moment for a given lift increment than that realized from deflection of a plain flap located at the wing trailing edge. This forward split flap in combination with the canard surface deflected for trim indicated a trim lift coefficient of 1.0 with an acceptable static margin at an angle of attack (approximately 13°) suitable for take-off or landing conditions.

INTRODUCTION

The National Aeronautics and Space Administration is currently conducting general research programs relative to improvement of the longitudinal and lateral stability and control characteristics associated with canard airplane configurations. Various canard configurations are currently under consideration in connection with the design of supersonic transports and high Mach number military aircraft, since these types of aircraft appear to offer some advantage with regard to aerodynamic efficiency at supersonic speeds. (See ref. 1.)

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The major problem areas associated with canard configurations occur at subsonic speeds where the following conditions tend to reduce the desirability of this type of airplane configuration: stalling of the canard control at moderate local angles of attack, adverse canard-control wing interference effects, and the inability to make use of wing trailing-edge flaps to aid in increasing the lift for take-off and landing attitudes. The use of high-lift devices on the canard control has been investigated and indicates promising results with regard to increasing trim-lift range and allowable center-of-gravity travel. (See refs. 2 and 3.) Increases in maximum lift and untrimmed maximum lift-drag ratio at subsonic speeds have also been obtained by use of deflected partial-span wing leading-edge chord-extensions. These chord-extensions have their root sections located at approximately the canard control vortex at the wing leading edge. (See ref. 4.) The problem of obtaining high lift at moderate angles of attack evolves from the fact that high-lift flaps located at the wing trailing edge produce large nose-down moments which the canard control is either unable to trim or, in order to trim, must be operated near or above its stalling point. Using variable-wing incidence to increase lift at moderate angles of attack has been considered (ref. 3) and appears to produce less resultant moment than trailing-edge flaps. The increased wing incidence, coupled with the canard flow field, could produce wing-tip losses resulting in loss of longitudinal stability at moderate angles of attack for wings having a low angle for maximum lift. The use of split flaps located ahead of the wing trailing edge, although not as efficient in producing lift as trailing-edge flaps, would produce resultant loads closer to the center of gravity of the configuration and may offer a means of obtaining lift at low angles of attack without producing large resultant nose-down moments.

The purpose of the present investigation was to provide information on the use of canard controls having leading-edge and trailing-edge flaps on an airplane configuration having a wing with a partial-span leading-edge chord-extension as a means of improving the control and maximum-lift characteristics of this type of configuration. Also investigated was the use of split flaps located at various wing-chord stations ahead of the trailing edge as a means of increasing configuration lift at low and moderate angles of attack without producing large nose-down pitching moments. The wing employed in the investigation had an aspect ratio of 3.0, a taper ratio of 0.143, and an NACA 65A004 airfoil section parallel to the plane of symmetry. Various canard controls, including a trapezoidal planform similar to the basic wing, a 60° delta planform, and a modified 60° delta planform, were investigated in combination with the basic-wing configuration and the wing configuration having split flaps located ahead of the wing trailing edge.

SYMBOLS

Data in this paper are referred to the wind-axis system, with the coefficients nondimensionalized by the area and mean aerodynamic chord of the basic wing. The moment reference point was located $0.225\bar{c}_w$ ahead of $\bar{c}_w/4$ for the wing for all tests unless otherwise noted. All control deflections are referenced to the fuselage reference line.

C_D — drag coefficient, $\frac{\text{Drag}}{qS_w}$

C_L — lift coefficient, $\frac{\text{Lift}}{qS_w}$

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_w\bar{c}_w}$

$C_{m_{\delta_c}}$ — canard-control effectiveness parameter, $\Delta C_m/\delta_c$

$C_{m_{\delta_{f,c}}}$ — canard-control trailing-edge-flap effectiveness parameter, $\Delta C_m/\delta_{f,c}$

$\bar{c}_c/4$ — quarter-chord point of mean aerodynamic chord of canard control

c_w — wing chord, ft

$\bar{c}_w$ — mean aerodynamic chord of wing, ft

$\bar{c}_w/4$ — quarter-chord point of mean aerodynamic chord of wing

q — dynamic pressure, lb/sq ft

S_w wing area, sq ft

α angle of attack, deg

ΔC_D incremental drag coefficient produced by deflection of wing split flap

ΔC_L incremental lift coefficient produced by deflection of wing split flap

ΔC_m incremental pitching-moment coefficient produced by deflection of wing split flap

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δ_c canard-control deflection, positive with trailing edge down, deg

$\delta_{f,c}$ canard-control trailing-edge flap deflection, positive with trailing edge down, deg

$\delta_{f,w}$ wing-lift-flap deflection, positive with trailing edge down, deg

$\delta_{n,c}$ canard-control leading-edge flap deflection, negative with leading edge down, deg

$\delta_{n,w}$ wing partial-span leading-edge chord-extension deflection, negative with leading edge down, deg

Subscript:

max maximum

Configuration designations:

W basic wing

B body

C_1 trapezoidal planform canard control

C_2 60° delta planform canard control

C_3 modified 60° delta planform canard control

MODELS

The model configurations and component parts are shown in figure 1. The body was a circular ogive, symmetrical in all planes, with a maximum diameter of 4.50 inches and a fineness ratio of 13.33. The basic wing had a trapezoidal planform similar to the basic wing of reference 4, an NACA 65A004 airfoil section parallel to the plane of symmetry, an aspect ratio of 3.0, a taper ratio of 0.143, and a leading-edge sweep angle of 38.52°. A partial-span leading-edge chord-extension which had a tip extension 20 percent of the basic wing-tip chord and a theoretical root extension 10 percent of the basic wing-root section was tested with the basic wing and was fixed at a deflection angle of -30°. The inboard chord of this extension was located 7.50 inches from the fuselage center line (fig. 1(a)). Hereinafter the partial-span leading-edge chord-extension will be referred to as the leading-edge chord-extension.

Details of the wing flaps are presented in figure 1(b). The trailing-edge plain flaps (designated herein as flaps I) were 20-percent-chord flaps with the leading edge located at the unswept 80-percent-chord line of the wing. The gap between the wing and the flap was sealed. Wing flaps II were 20-percent-chord split flaps with a leading-edge location along the wing 60-percent-chord line. Wing flaps III were also 20-percent-chord split flaps and had the leading edge located along the 40-percent-chord line of the wing. All flap deflections are referenced to the fuselage reference plane.

The trapezoidal canard control was of flat-plate section similar in planform to the basic wing and had a total planform area equal to 16 percent of the total basic wing area. The leading edge of this control could be deflected to a maximum of -30°; the hinge line for this leading-edge flap was located at the 20-percent-chord line. The trailing-edge flap used on this control was hinged at the 80-percent-chord line and was a full-span plain flap with a sealed gap. The 60° delta planform control was also of flat-plate section and had a total area equal to 16 percent of the total basic wing area. The hinge line for the trailing-edge flap of this control was located 1.55 inches from the unswept trailing edge, and the flap included the tip section of this control, 1.75 inches in from the tip. (See fig. 1(b).) The modified 60° delta planform control was made by removing the trailing-edge flap from the basic 60° delta planform, and consequently had a blunt trailing edge. The hinge line for deflection of the trapezoidal and 60° delta planform controls corresponded to the quarter-chord point of the mean aerodynamic chord for each control. The 60° modified delta control was hinged at the same point as the 60° delta control surface. A photograph of the configuration having a 60° delta canard and a wing with leading-edge chord-extension deflected -30° is presented as figure 2.

TESTS AND CORRECTIONS

The present investigation was conducted in the Langley 300-MPH 7- by 10-foot tunnel at a dynamic pressure of approximately 57 pounds per square foot. The average test Reynolds number based on the wing mean aerodynamic chord was approximately 2.10×10^6. The model was mounted on a single support strut and was tested through an angle-of-attack range from -2° to 26° and at zero sideslip.

Blockage corrections determined by the method of reference 5 have been applied to the dynamic pressure and drag, and jet-boundary corrections determined by the method of reference 6 have been applied to the angle of attack and the pitching-moment and drag coefficients. Drag coefficients have also been corrected for tunnel buoyancy effects.

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RESULTS AND DISCUSSION

Figures 3 to 19 present the basic data for the configurations of the investigation, and a detailed listing of the various combinations tested is presented in table I. Figures 20 to 23 present a summary of some of the results of the investigation with a detailed listing also presented in table I.

Longitudinal Stability

The problem of nonlinear variation of pitching moment with increasing lift associated with canard configurations at subsonic speeds is of prime interest both from the standpoint of determining center-of-gravity location and the amount of control power required for trim. From the present investigation it may be seen, for example, that the configuration having the trapezoidal canard control and the basic wing has a static margin of approximately 1 percent $\bar{c}_w$ at low lifts and a rather abrupt increase in stability occurring at an angle of attack of about 12°. (See fig. 3 and ref. 4.) This low value of stability at low lifts is permissible because of the increasing stability with increasing lifts noted for this configuration and would be desirable from supersonic-design requirements. Since the increase in static margin at a high Mach number should be less than 20 percent (see ref. 7), only slight deflection of the control surface would be required for trim at the cruise condition. The abrupt increase in stability occurring above an angle of attack of 12° for this configuration, however, indicates the possibility of a control problem existing at the high lift coefficients desired for take-off or climbout conditions at subsonic speeds. A delta canard and trapezoidal wing arrangement, as presented in reference 4, has indicated a reverse condition. For the same moment reference point as the trapezoidal canard configuration previously mentioned, the delta-canard configuration had a static margin of 6 percent $\bar{c}_w$ at low lifts and became neutrally stable or unstable at higher lifts. (See fig. 10.) In order to make this configuration stable at the higher lift coefficients desired at subsonic speeds, a forward movement of the center of gravity would be required. However, the configuration would become excessively stable at supersonic speeds and thus require higher control deflection for trim at the cruise condition.

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Changing the 60° delta canard planform to a modified 60° delta planform tended to alleviate the decrease in stability noted for the 60° delta canard configuration at moderate lifts, although the slight pitch-up tendency was still noted for this planform between angles of attack of approximately 15° and 20° for $\delta_c = 0^{\circ}$. (See fig. 13.) The indication is, however, that proper canard planform, designed with consideration of the longitudinal stability characteristics noted for the wing alone, should result in more linear pitching-moment variation throughout the range of lift coefficients obtainable.

Longitudinal Control

A summary of the control properties of the configuration having the trapezoidal canard surface is presented in figures 20 and 21, and a summary of the control characteristics of the configuration having the 60° delta canard surface is presented in figure 22. For the most part, the discussion on longitudinal control will be confined to these summary figures.

The longitudinal control characteristics associated with total deflection of a trapezoidal canard or delta canard control presented in reference 4 indicate that the configuration having the trapezoidal planform had higher values of control effectiveness than the delta configuration at low angles of attack. The control effectiveness for the configuration having the delta canard control, however, held up for higher control deflection and to higher angles of attack than did the configuration having the trapezoidal canard control. The loss of control for the trapezoidal canard at moderate angles of attack, and correspondingly moderate lifts, is indicated in figure 20(a) of the present investigation for the condition of canard leading- and trailing-edge flaps at 0° deflection.

Use of the trailing-edge flap on the trapezoidal canard control, however, as indicated in figure 20(a), is seen to have good control characteristics for the canard at 0° deflection, and also indicates higher control effectiveness than that realized by deflection of the total trapezoidal canard control at angles of attack above 10° (fig. 20). Use of the canard trailing-edge and leading-edge flap deflections without deflection of the total canard surface indicates trim up to the maximum attainable C_L (fig. 20(a)). The effects of the addition and deflection of the leading-edge chord-extension to the basic wing on the lift and longitudinal stability of the trapezoidal canard configuration are presented in figure 21; this figure indicates that the addition of the leading-edge chord-extension increased $C_{L,max}$ from approximately 1.03 to 1.20. Use of the trapezoidal canard control at a $\delta_c = 0^{\circ}$, with the leading-edge and trailing-edge flaps deflected -20° and 20°, respectively, in combination with the wing having leading-edge chord-extension deflected -30°, indicates trim lift up to a C_L of 1.15, with a reasonable level of longitudinal stability existing at trim.

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A comparison between total canard deflection and canard trailing-edge flap deflection on the control effectiveness for the 60° delta canard configuration indicates similar variation of control effectiveness with angle of attack for either method of control. (See fig. 22.) Low values of $C_{m_{\delta_c}}$ and $C_{m_{\delta_{f,c}}}$ are seen to hold up to the maximum angle of attack attained, as previously noted in reference 4. Figure 13 presents the longitudinal control characteristics of the modified 60° delta canard and indicates essentially the same control characteristics as the 60° delta canard configuration, except that earlier stalling occurs for the modified canard surface.

Longitudinal Characteristics of Wing Flaps

The inability of canard airplanes to take advantage of high lift coefficients provided by wing trailing-edge flaps for take-off or landing at moderate angles of attack is attributed primarily to the lack of sufficient canard-control power to trim the large nose-down pitching moments which usually accompany wing-flap deflection. This problem is illustrated in reference 8 and in figure 14(a) of the present investigation for the condition of a plain wing flap located at the trailing edge. For take-off or landing attitudes between 12° and 16°, this trailing-edge flap is seen to produce lift coefficients between 1.0 and 1.2. The nose-down pitching moment, however, is considerably out of trim even at low lifts with the trapezoidal canard configuration operating near and above stalled conditions. The configuration having the wing with the trailing-edge flap in combination with the 60° delta canard surface indicates similar results (fig. 14(b)) and because of the lower value of the lift-curve slope for the delta canard control (ref. 4), this configuration is further out of trim than the trapezoidal canard configuration. Use of a partial-span split flap, designated

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flap II (fig. 1(b)), located between the 60-percent- and 80-percent-wing-chord stations appeared to offer a means of obtaining increased lift without producing nose-down moments as large as those obtained with the use of the plain flap located at the trailing edge. A comparison of figures 14 and 15 indicates that the split flap located forward of the wing trailing edge provided somewhat less gain in lift throughout the test angle-of-attack range than provided by the trailing-edge plain flap; however, nose-down pitching moments are considerably less than those noted for the trailing-edge flap, and of a magnitude which the canard control should be able to trim. Figure 16 presents the effectiveness of the trapezoidal canard control in producing trim in conjunction with wing split flaps II deflected 40° and 30°, and indicates that this canard control, deflected 5° in combination with canard leading-edge flap deflection of -20° and canard trailing-edge flap deflection of 20°, was able to trim the configuration at a lift coefficient of approximately 1.0 with an acceptable static margin at an angle of attack (approximately 13°) suitable for take-off or landing conditions.

Similar results are indicated for the delta canard and trapezoidal wing arrangement; however, a control reversal is noted for low deflection of wing split flap II (fig. 17). Considerable nonlinearity in the variation of pitching-moment coefficient with lift coefficient is noted for the delta canard control deflected in combination with the wing split flap and is primarily a result of the higher canard deflections required for trim than were necessary for the trapezoidal canard control. (See fig. 18.)

Figure 19 presents a comparison of the lifting characteristics of wing split flaps II and III and indicates considerable loss of lift for a given deflection as the flap is moved forward on the wing. The nose-down pitching moment is considerably less for the most forward flap location, as would be expected. The most forward flap, however, is apparently of small value as a result of the small amount of lift and excessive drag produced for extremely large flap deflections. Also, from unpublished results on a similar type of flap, negative lift increments were noted for flap deflections up to approximately 20°. This most forward flap, however, may possibly have application as a drag brake in landing.

The incremental increases in C_L, C_D, and C_m realized by deflection of wing split flap II are presented in figure 23. For the lowest flap deflection of 10°, a control reversal is noted, in that negative lift and accompanying positive pitching moment are prevalent throughout the angle-of-attack range. The highest flap deflection is seen to produce a value of ΔC_L of approximately 0.20 in the moderate and high angle-of-attack regions when accompanied by -30° deflection of the wing leading-edge chord-extension. Reductions in drag are also realized for this configuration when compared with the configuration having the leading-edge chord-extension off. As previously noted, the nose-down pitching moments per degree of deflection of wing split flap II appear to be considerably less than those noted from deflection of the trailing-edge plain flap. (See fig. 14.)

SUMMARY OF RESULTS

An investigation has been conducted at low subsonic speeds on the use of canard controls having leading- and trailing-edge flaps on an airplane configuration having a wing with a partial-span leading-edge chord-extension as a means of improving the control and maximum-lift characteristics. Also investigated was the use of split flaps located at various wing-chord stations ahead of the trailing edge. Results of this investigation may be summarized as follows:

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1. Considerable improvement in longitudinal stability, and reduction in the nonlinear variation of pitching moment with increasing lift characteristic of canard configurations, appears to be possible by use of a canard planform which is designed with consideration of the longitudinal stability characteristics noted for the wing alone.

2. For a trapezoidal canard planform, higher values of control effectiveness at high angles of attack were obtained by using a trailing-edge flap than by deflecting the total canard surface. The magnitude of control effectiveness at low angles of attack, however, was considerably less for the canard trailing-edge flap than for the total canard surface. Comparison of the control effectiveness associated with a 60° canard planform and a trailing-edge flap located on this canard surface indicates a similar variation with angle of attack for both controls, although the magnitude of control effectiveness was lower for the canard trailing-edge flap control than for the case in which the total canard surface was deflected.

3. The use of a wing with a partial-span leading-edge chord-extension on a configuration having either the trapezoidal or the delta canard control indicated improvement in longitudinal stability at high lift coefficients and increased the maximum lift coefficient obtainable.

4. Use of a wing split flap having its leading edge located along the 60-percent-chord line produced less resultant nose-down moment for a given lift increment than that realized from deflection of a plain flap located at the wing trailing edge. This forward split flap in combination with the canard surface deflected for trim indicated a

trim lift coefficient of 1.0 with an acceptable static margin at an angle of attack (approximately 13°) suitable for take-off or landing conditions.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., February 2, 1962.

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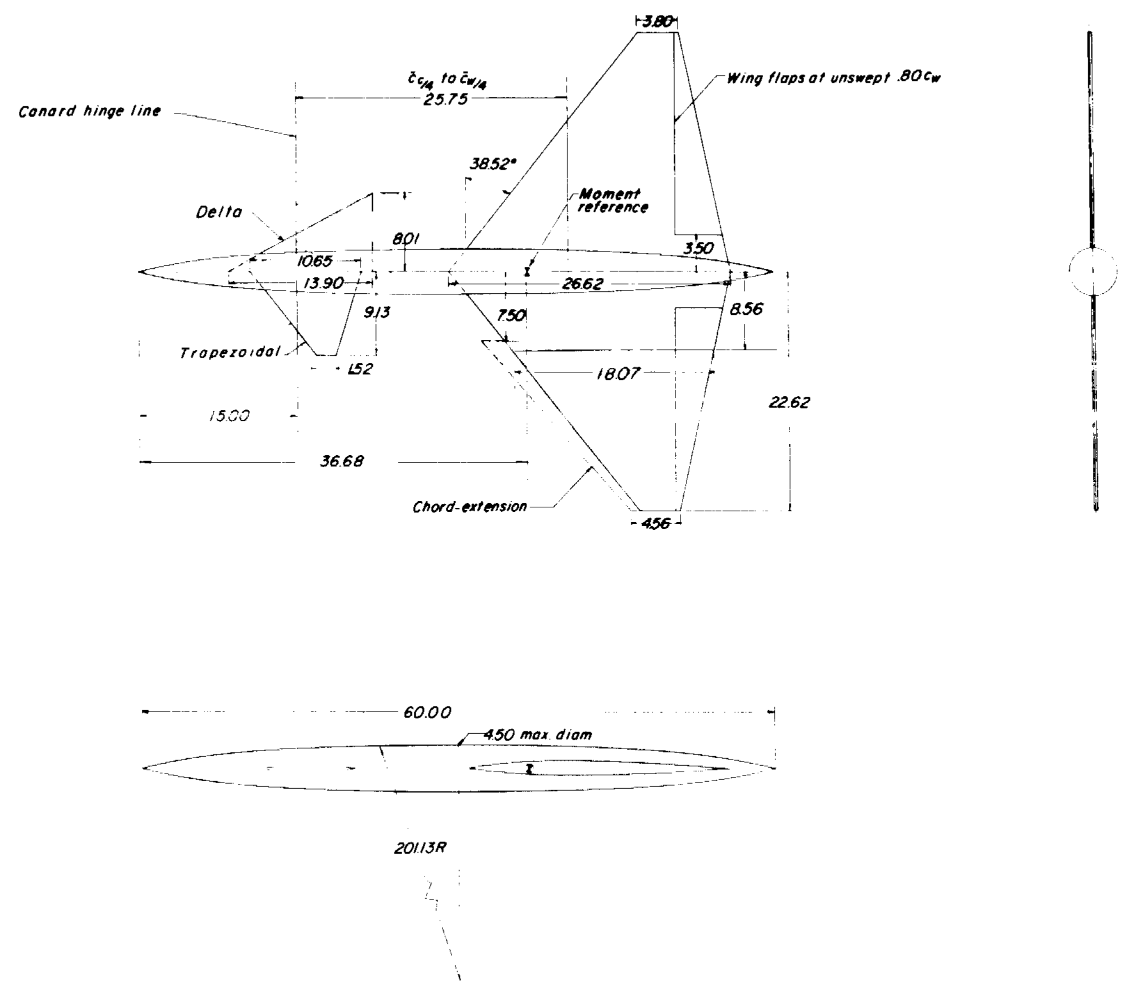
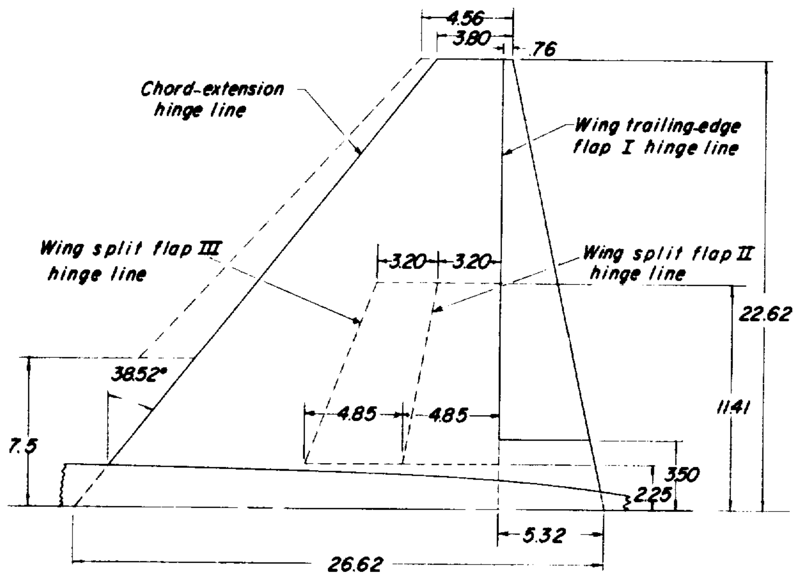
TABLE I.- INDEX TO FIGURES PRESENTING DATA

Configuration	δ_c, deg	$\delta_{n,c}$, deg	$\delta_{f,c}$, deg	$\delta_{n,w}$, deg	$\delta_{f,w}$, deg	Wing-lift flap	Figure
Basic data							
WBC_1	0	0	0, 10, 20, 30	Off	0	None	3
↓	0	-20, -30	20, 30	↓	↓	↓	4
	5	0, -20, -30	0, 10, 20				5
	10	0, 20	0, 10				6
	0, 5	-20	0, 20	Off, -30			7
	5	0, -20, -30	0, 20	-30			8
	10	0, -20	0, 10	-30			9
WBC_2	0	None	0, 10, 20	-30			10
↓	5	None	0, 10, 20	-30			11
	10, 15, 20	None	10, 20	-30			12
WBC_3	0, 10, 20	None	None	-30			13
WB	Off	Off	Off	Off, 0	0, 18	I	14(a)
WBC_1	0, 20	0	0	-30	18	↓	14(a)
WB	Off	Off	Off	Off	0, 18		14(b)
WBC_2	0, 20	None	0	Off	18		14(b)
WBC_1	0	0	0	-30	20, 30, 40	II	15
↓	0, 5	0, -20	0, 20	-30	30, 40	↓	16
WBC_2	0	None	0	Off, -30	10, 20, 30		17
↓	0, 15, 20	None	0, 10, 20	-30	30, 40		18
WBC_3	5, 20	None	None	-30	30, 40	II and III	19
Summary data							
WBC_1	0, 5, 10	0, -20	0, 10, 20, 30	Off	0	None	20(a)
↓	0, 5, 10	0	10, 20, 30	↓	↓	↓	20(b)
	0, 5	-20	20	Off, -30			21
WBC_2	0, 5, 10, 15	None	0, 10, 20	-30			22
WBC_1	0	0	0	Off, -30	10, 20, 30	II	23



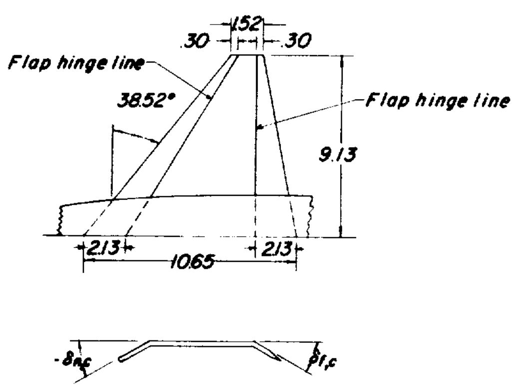
(a) Complete models.

Figure 1.- Geometric characteristics of configurations. All dimensions used are in inches unless otherwise noted.

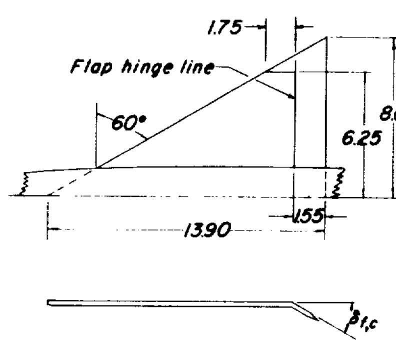


Wing lift flaps and leading-edge chord-extension

Note: Modified delta canard, C_3, corresponds to delta canard, C_2, with trailing-edge flap removed.



Trapezoidal canard



Delta canard

(b) Details of model components.

Figure 1.- Concluded.

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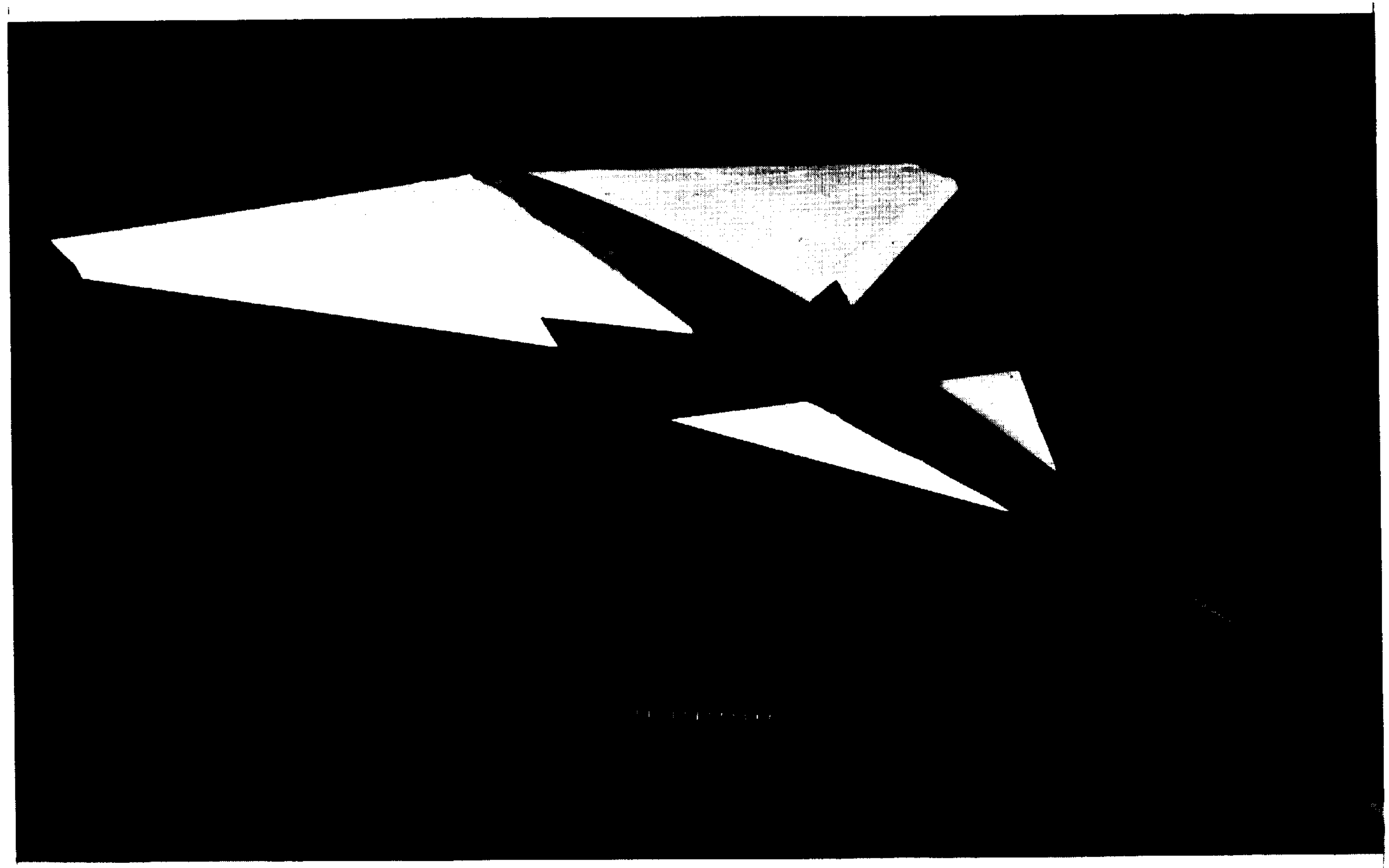

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Figure 2.- Photograph of configuration having a 60° delta canard and wing with leading-edge chord-extension deflected -30°, mounted in the Langley 300-mile-per-hour 7- by 10-foot tunnel.

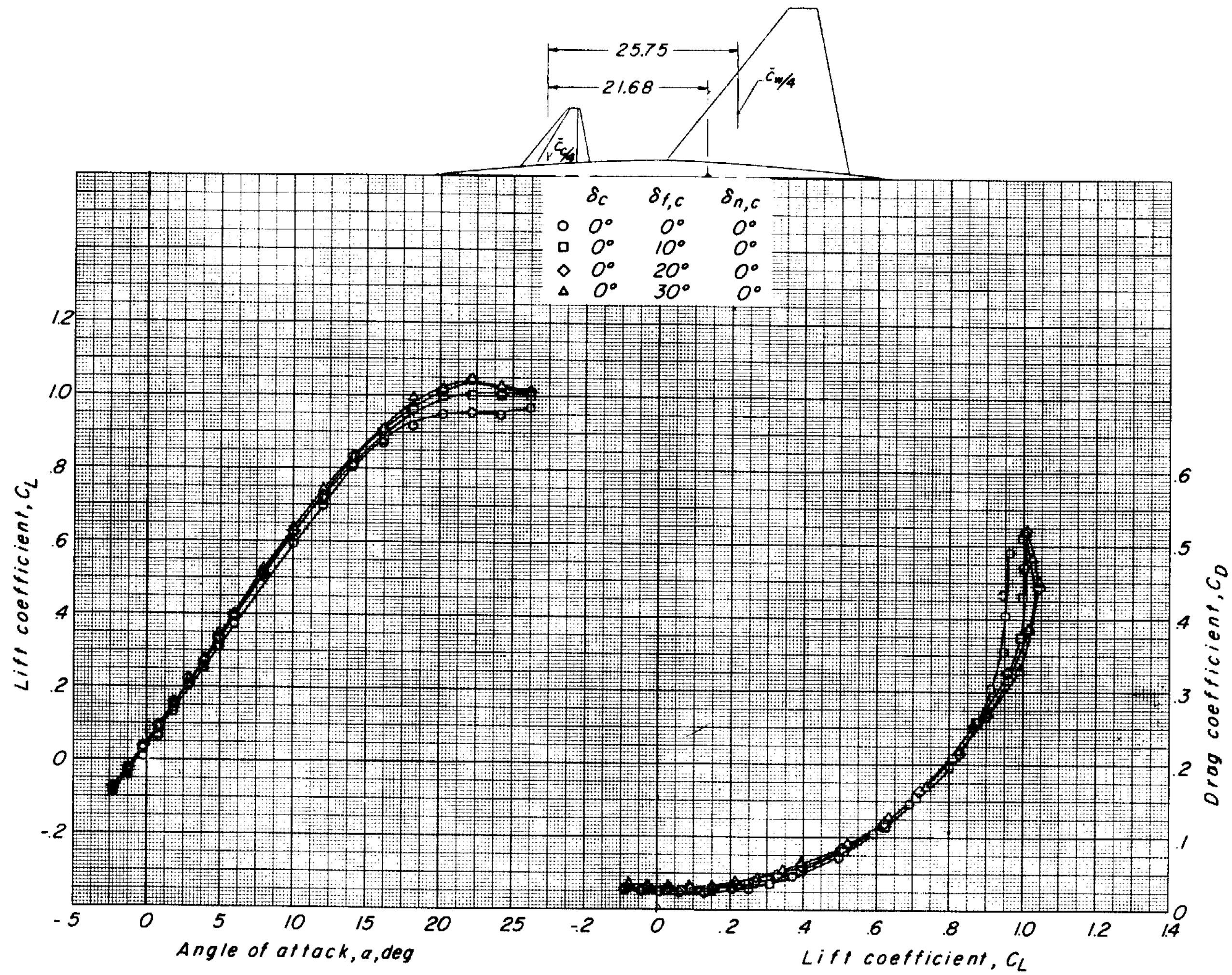

Figure 3.- Longitudinal aerodynamic characteristics of configuration having basic wing and having trapezoidal canard surface at zero deflection with trailing-edge flap control. $\delta_{f,w} = 0^{\circ}$; $\delta_{n,w}$ = Off.

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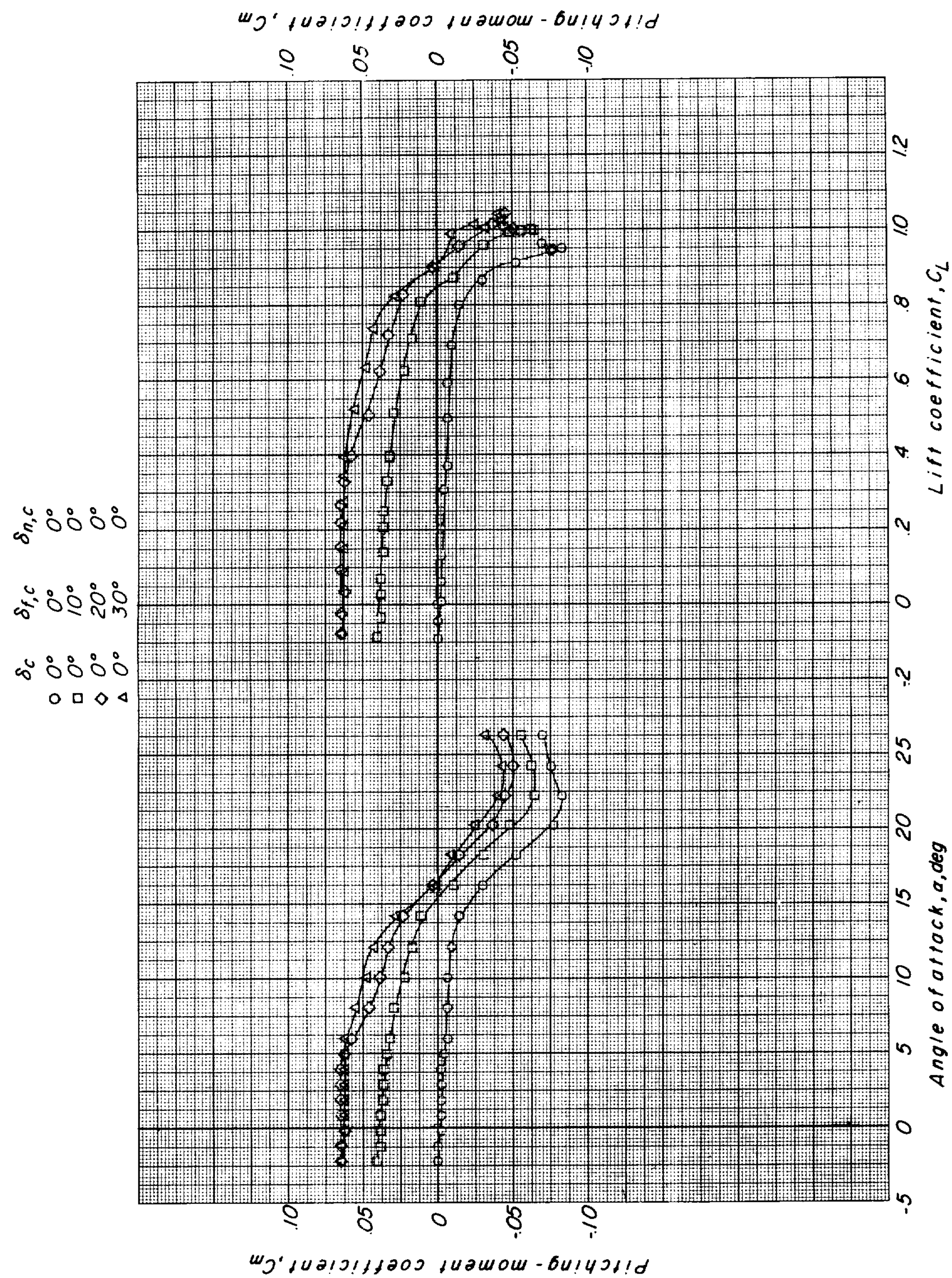


Figure 3.- Concluded.

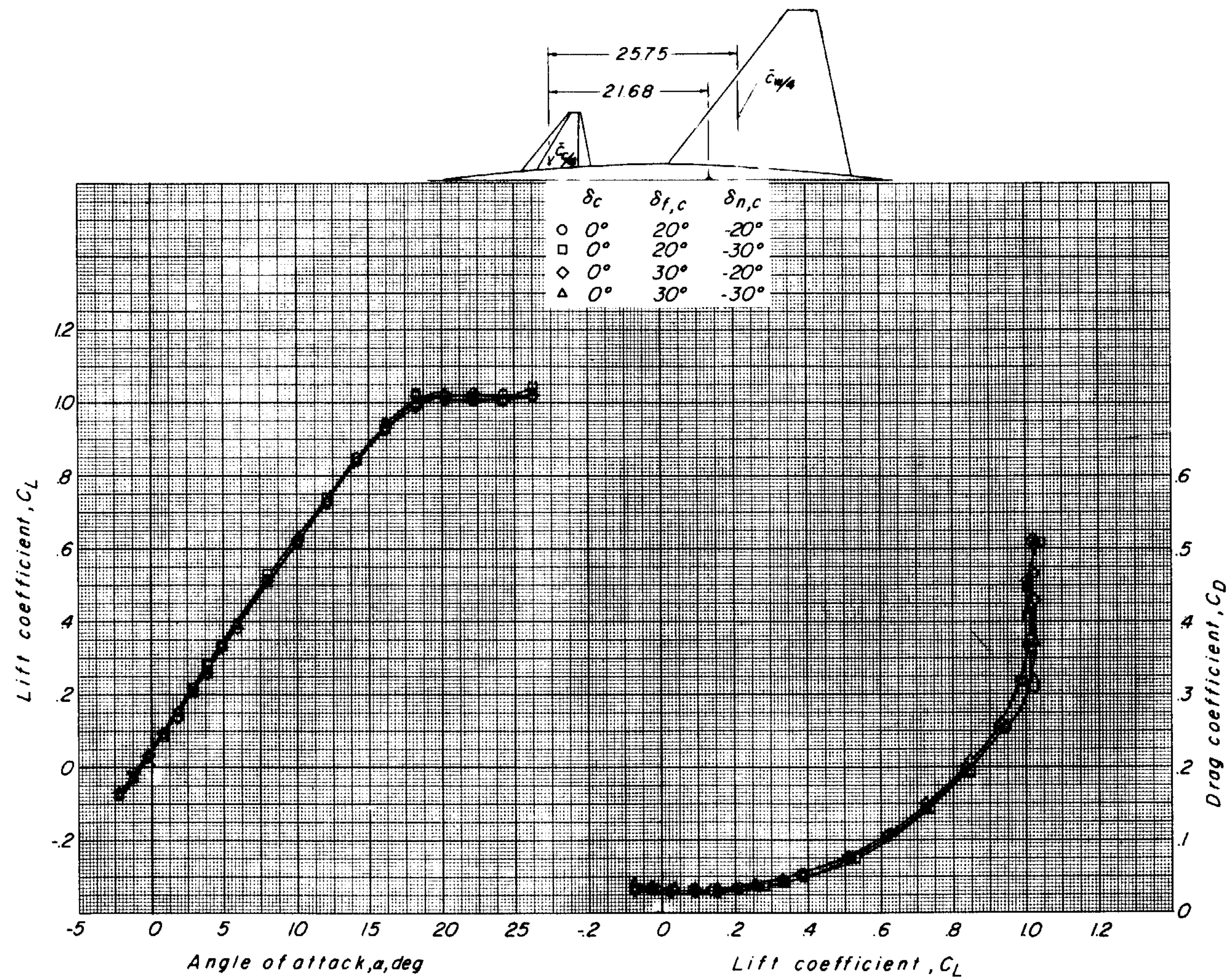


Figure 4.- Longitudinal aerodynamic characteristics of configuration having basic wing and having trapezoidal canard surface at zero deflection with trailing-edge and leading-edge flap control. $\delta_{f,w} = 0^{\circ}$; $\delta_{n,w}$ = Off.

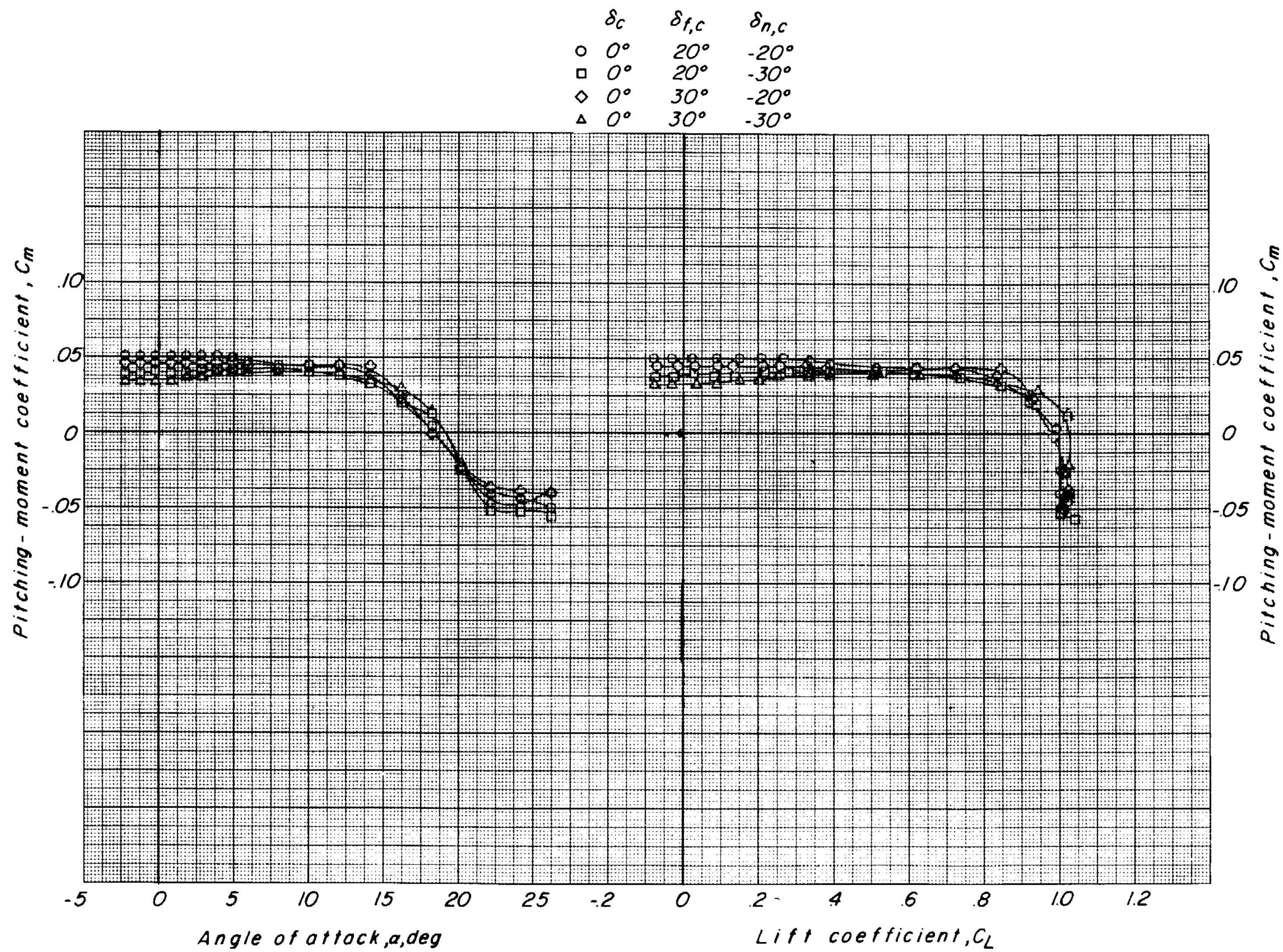


Figure 4.- Concluded.

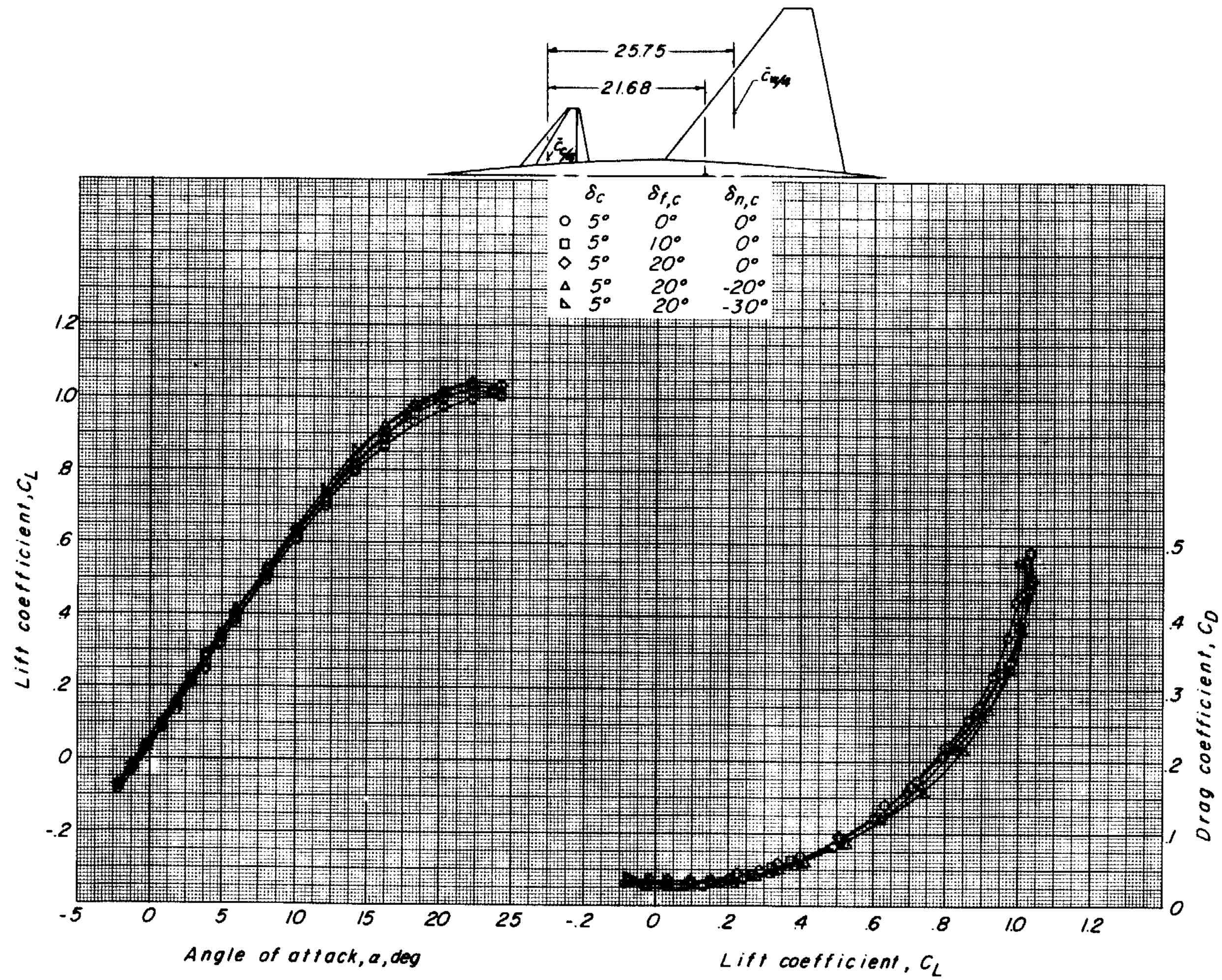


Figure 5.- Longitudinal aerodynamic characteristics of configuration having basic wing and having trapezoidal canard surface at 5° deflection with trailing-edge and leading-edge flap control. $\delta_{f,w} = 0^{\circ}$; $\delta_{n,w}$ = Off.

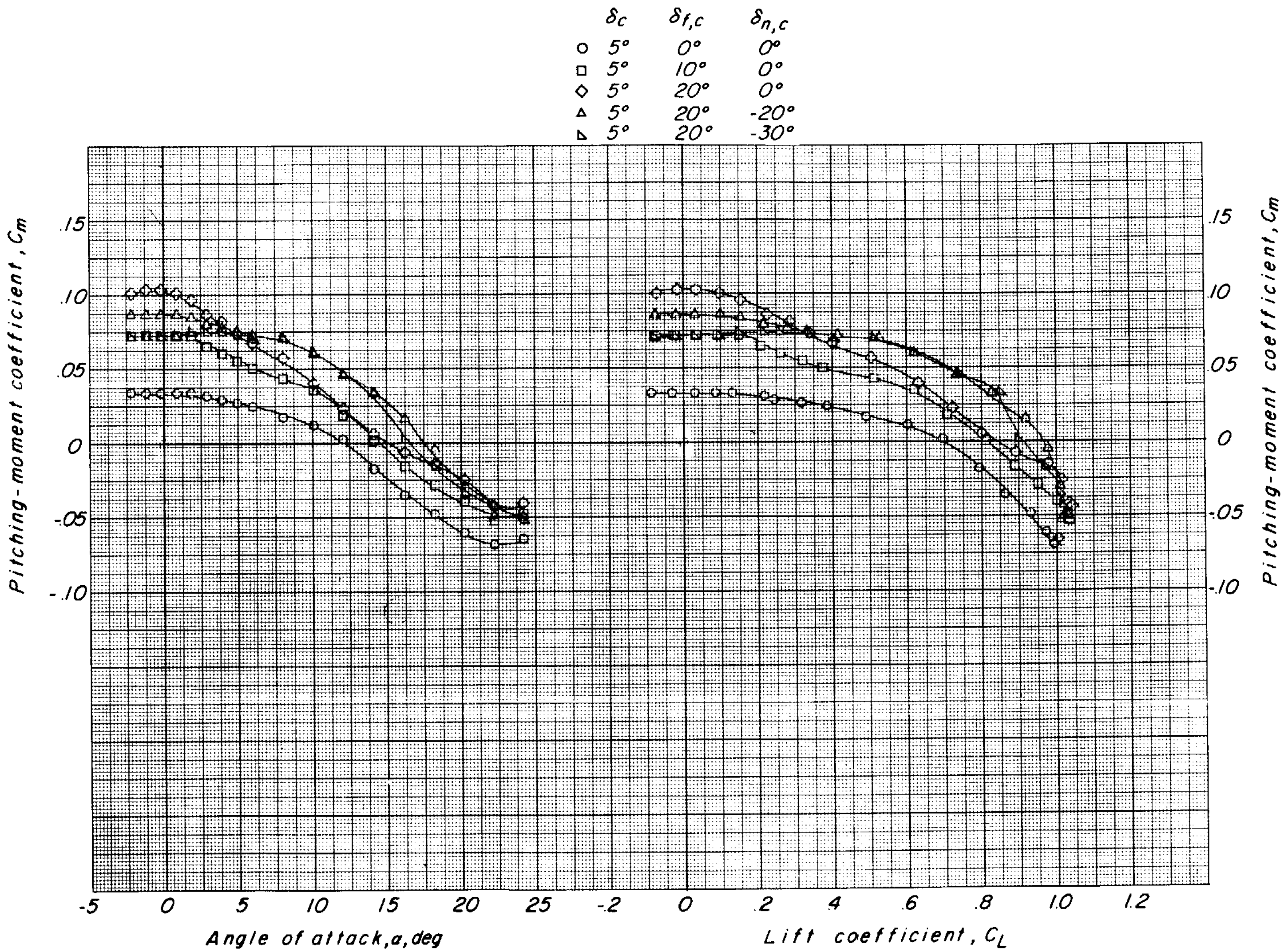


Figure 5.- Concluded.

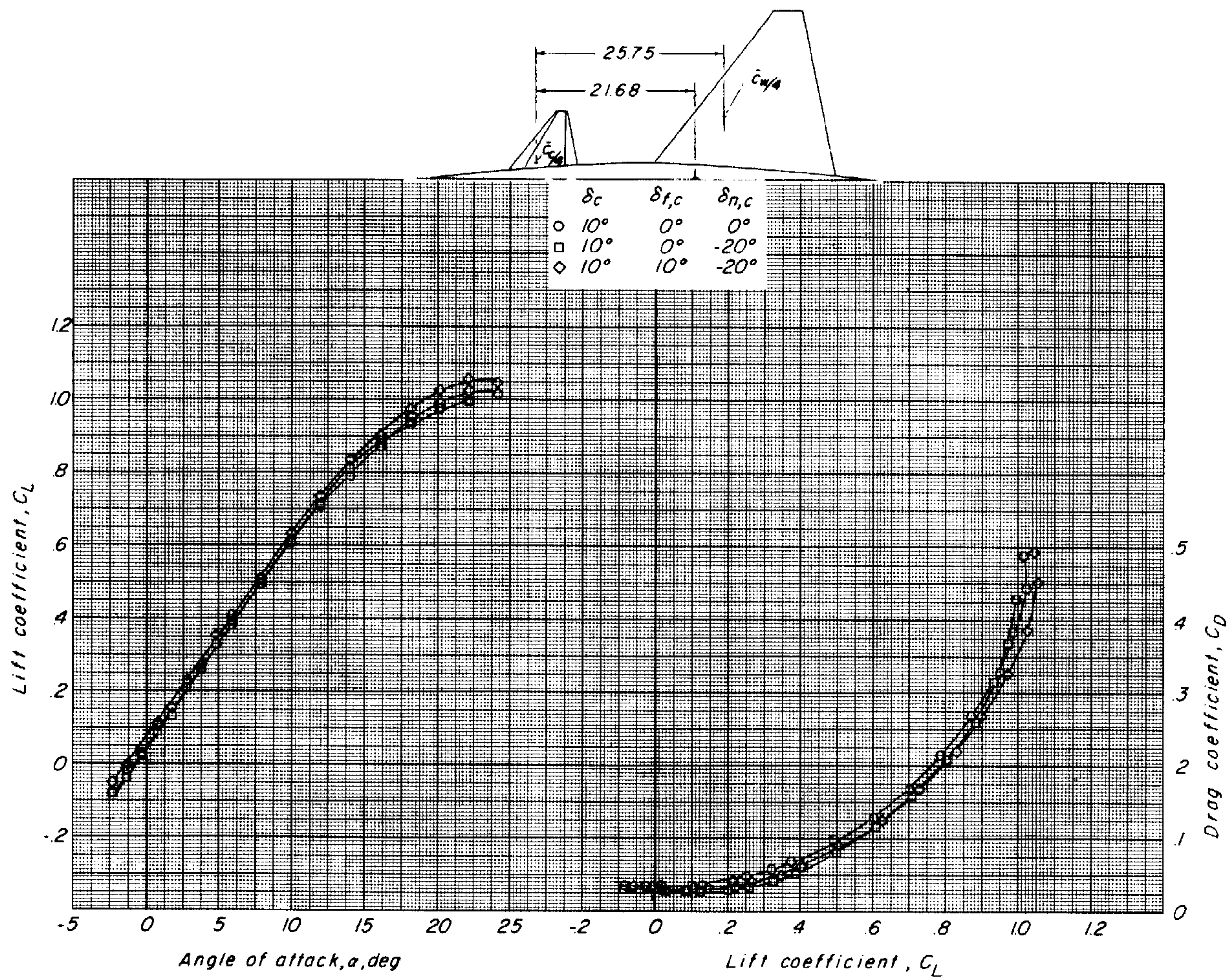
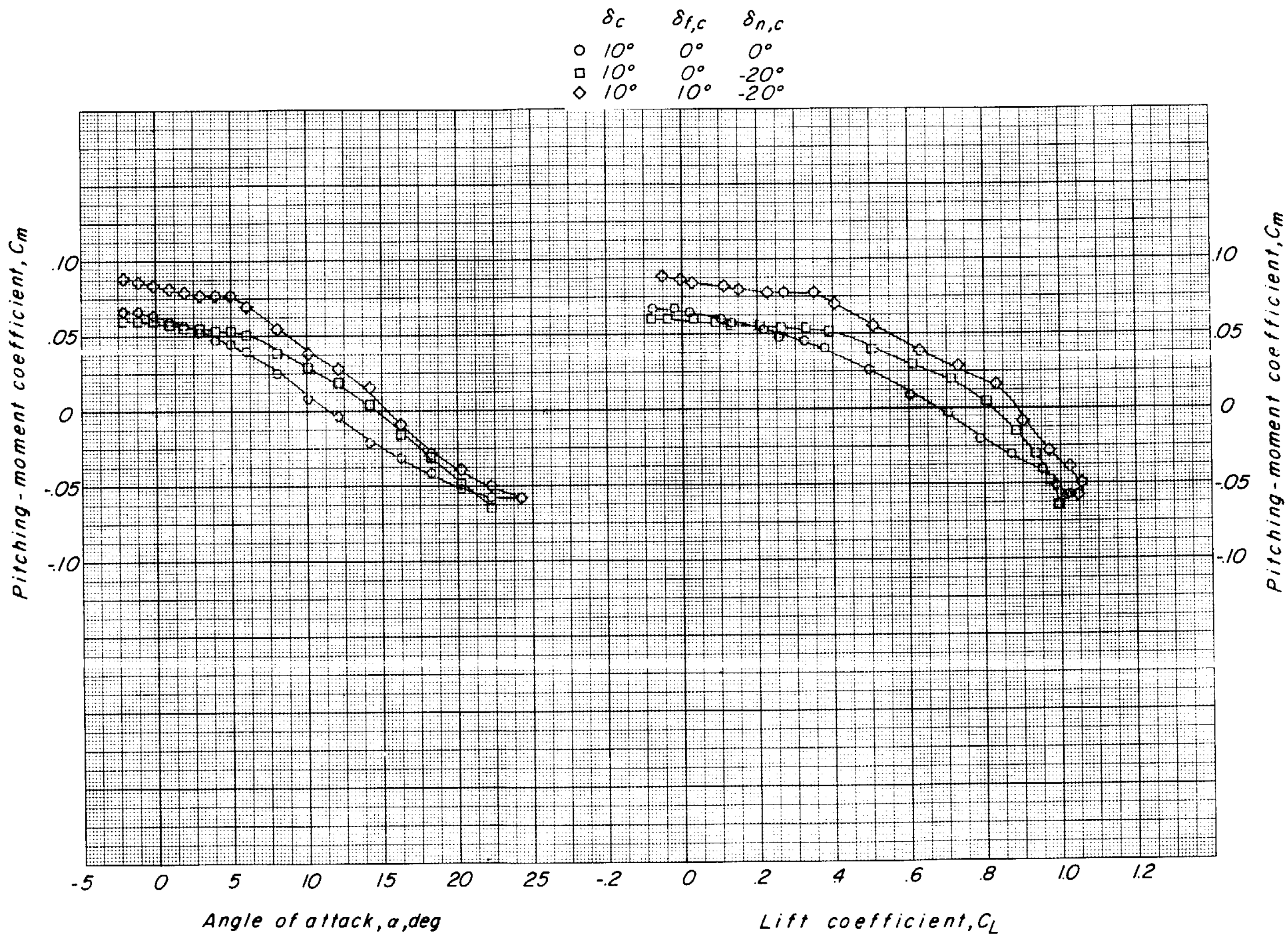


Figure 6.- Longitudinal aerodynamic characteristics of configuration having basic wing and having trapezoidal canard surface at 10° deflection with trailing-edge and leading-edge flap control. $\delta_{f,w} = 0^\circ$; $\delta_{n,w}$ = Off.



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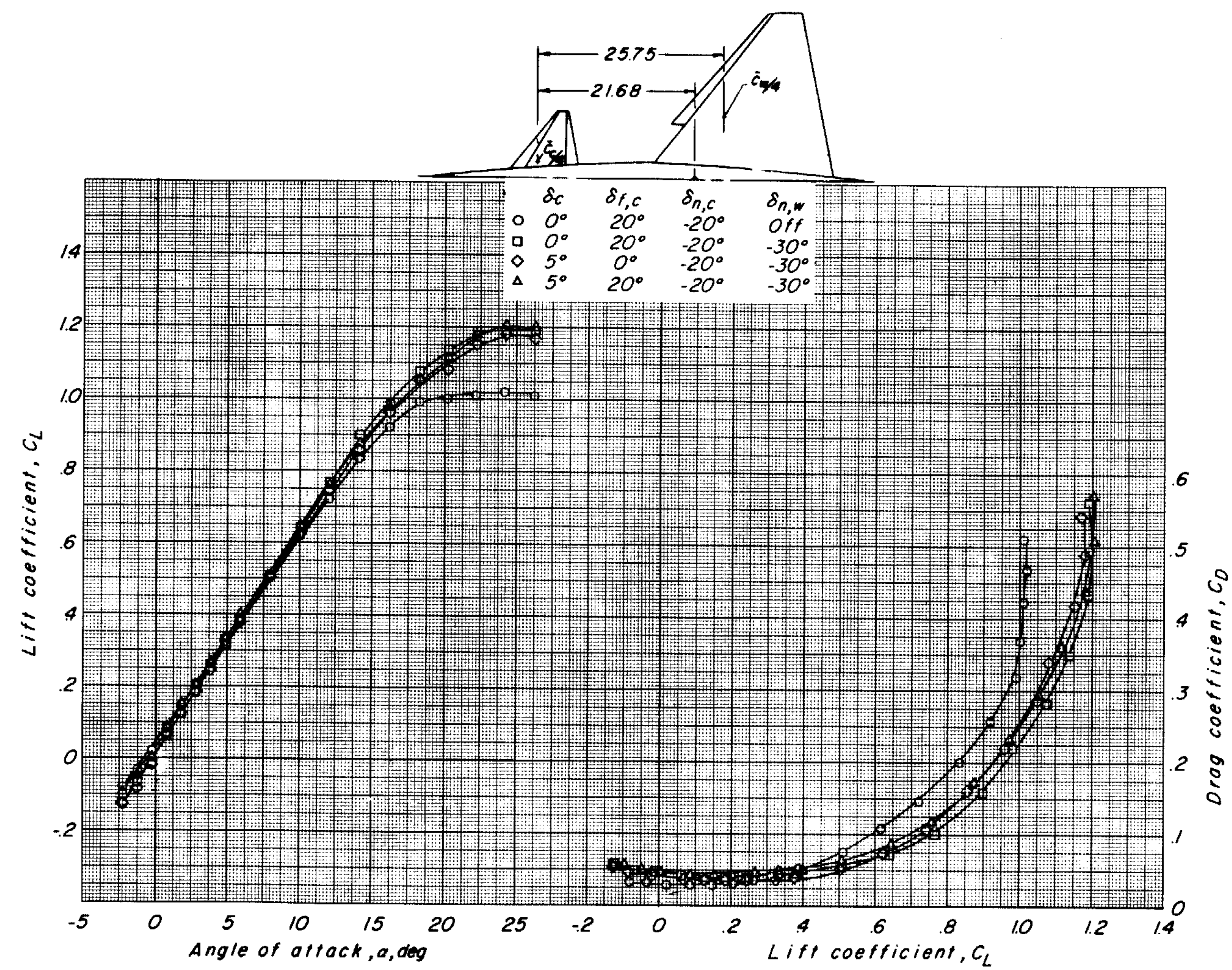


Figure 7.- Longitudinal aerodynamic characteristics of configuration having wing with and without partial-span leading-edge chord-extension and having trapezoidal canard surface with trailing-edge and leading-edge flap control. $\delta_{f,w} = 0^{\circ}$.

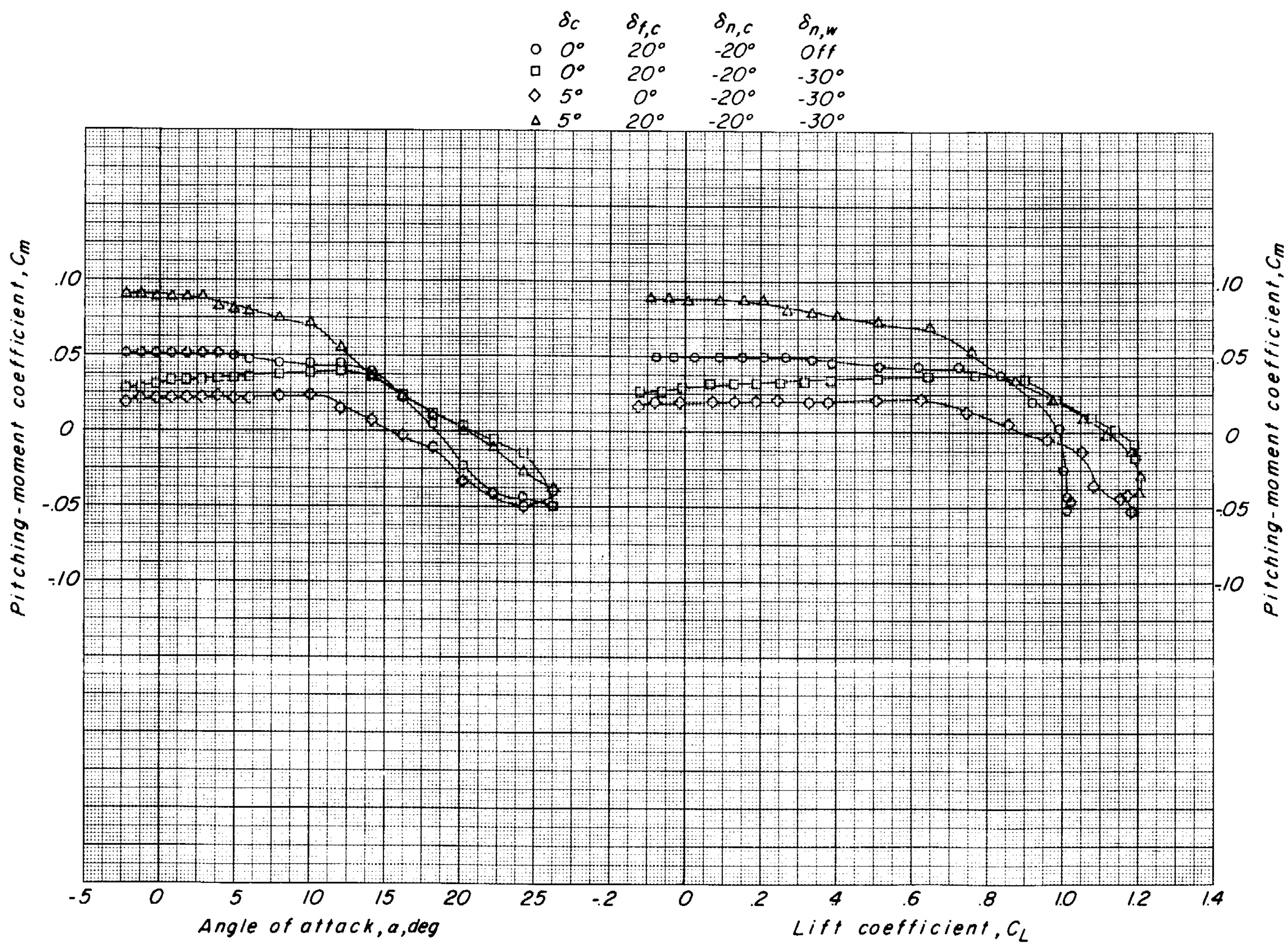


Figure 7.- Concluded.

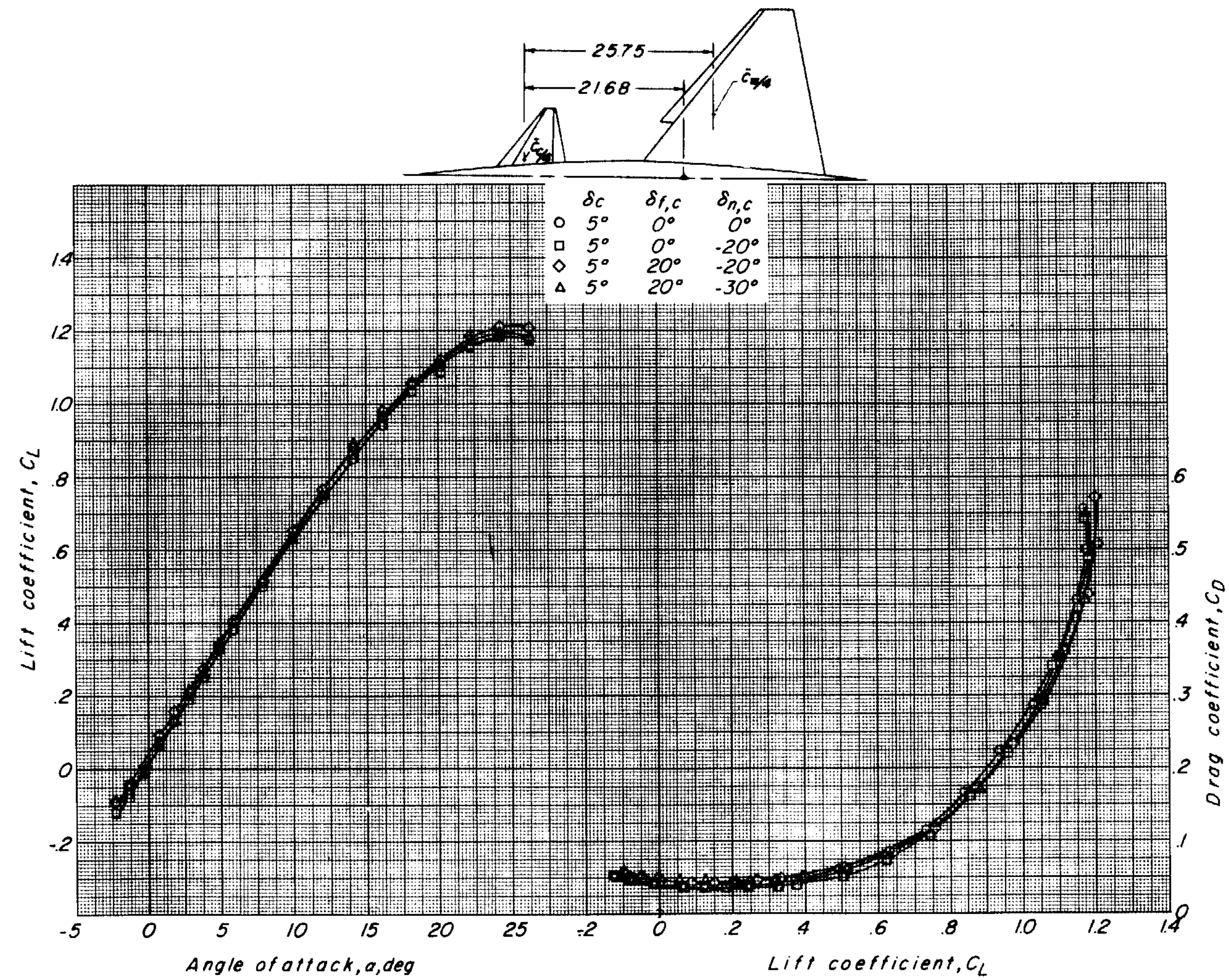
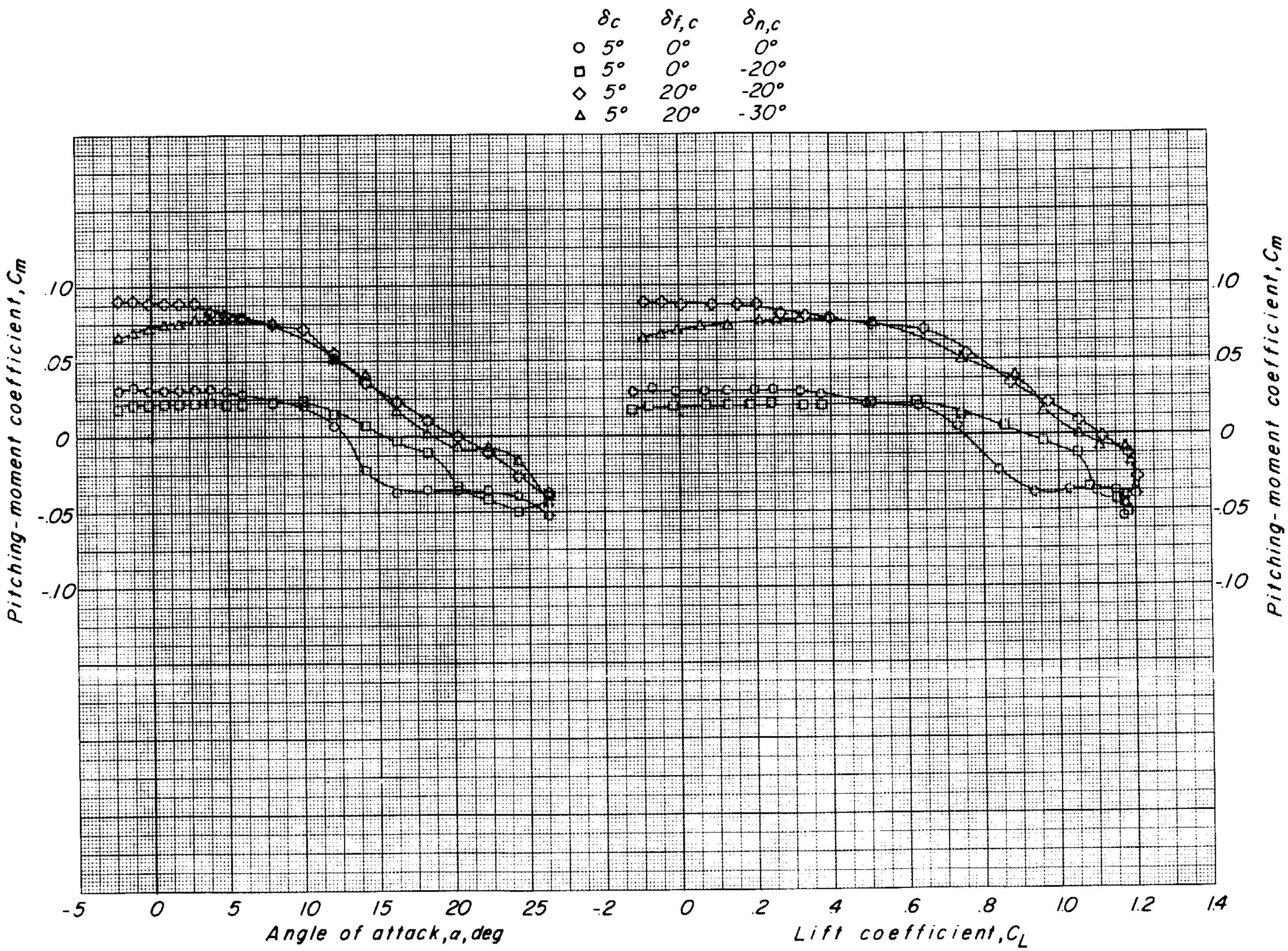


Figure 8.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having trapezoidal canard surface at 5° deflection with trailing-edge and leading-edge flap control. $\delta_{n,w} = -30^\circ$; $\delta_{f,w} = 0^\circ$.



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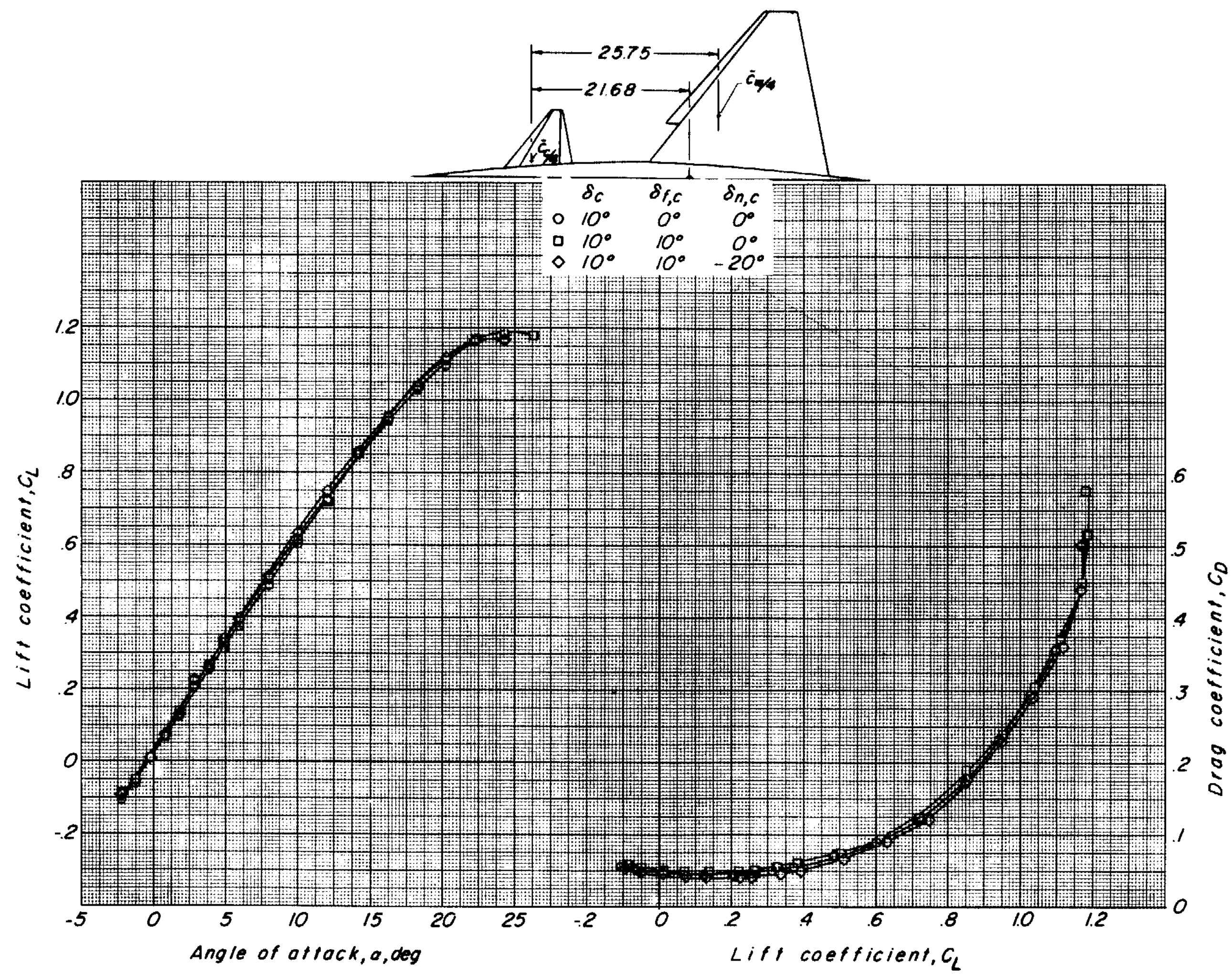
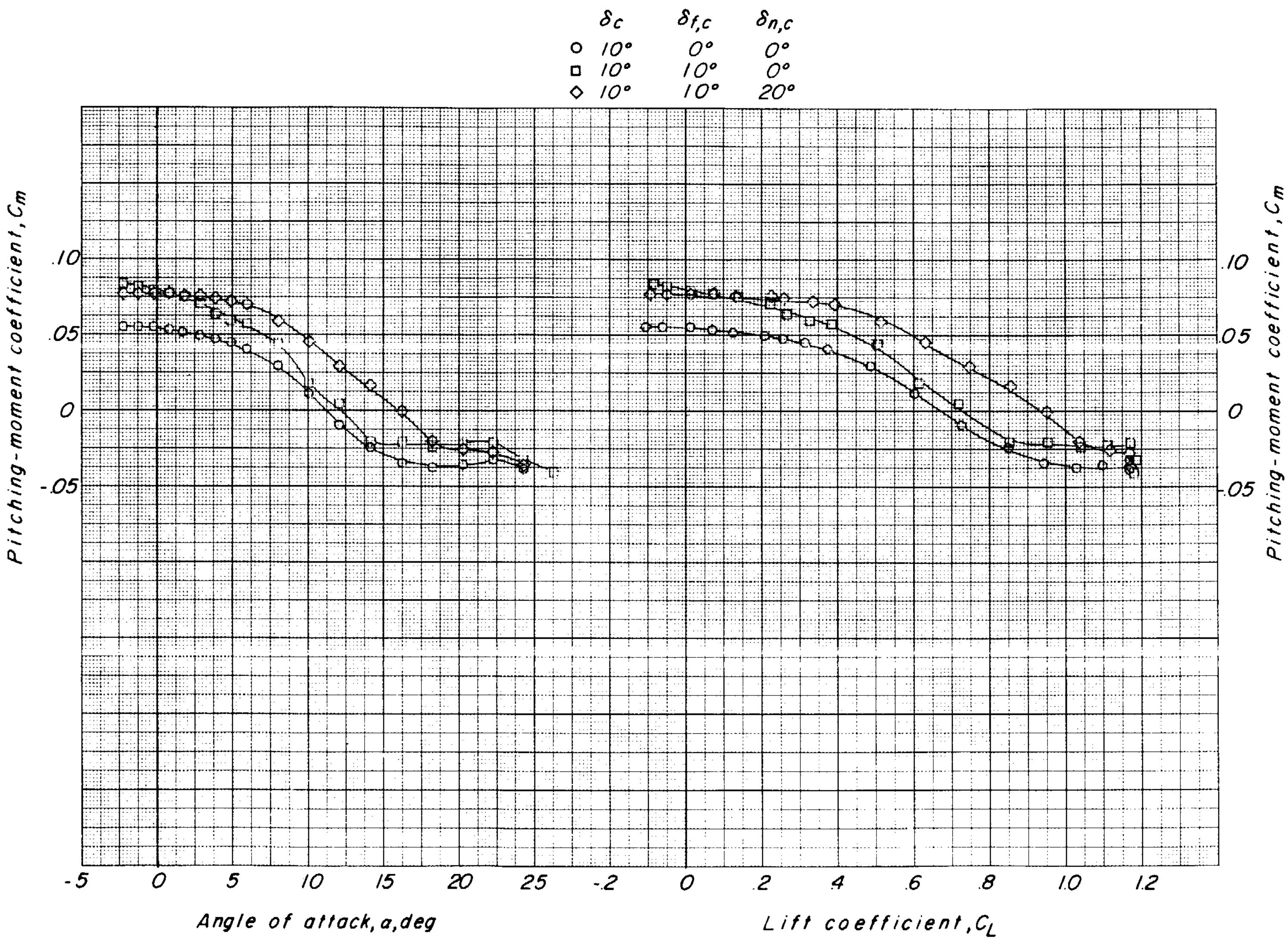


Figure 9.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having trapezoidal canard surface at 10° deflection with trailing-edge and leading-edge flap control. $\delta_{n,w} = -30°$; $\delta_{f,w} = 0°$.



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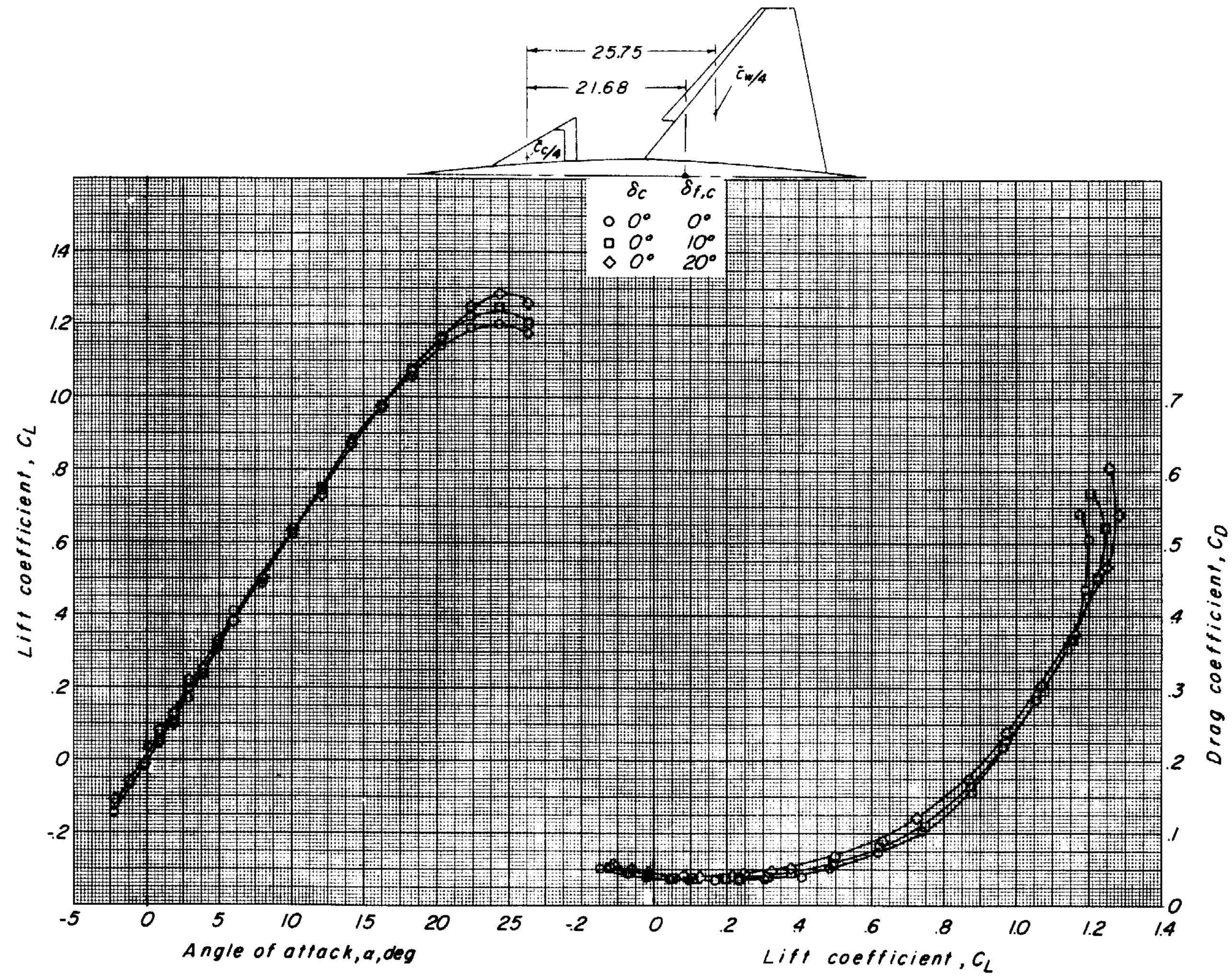


Figure 10.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having delta canard surface at 0° deflection with trailing-edge flap control. $\delta_{n,w} = -30°$; $\delta_{f,w} = 0°$.

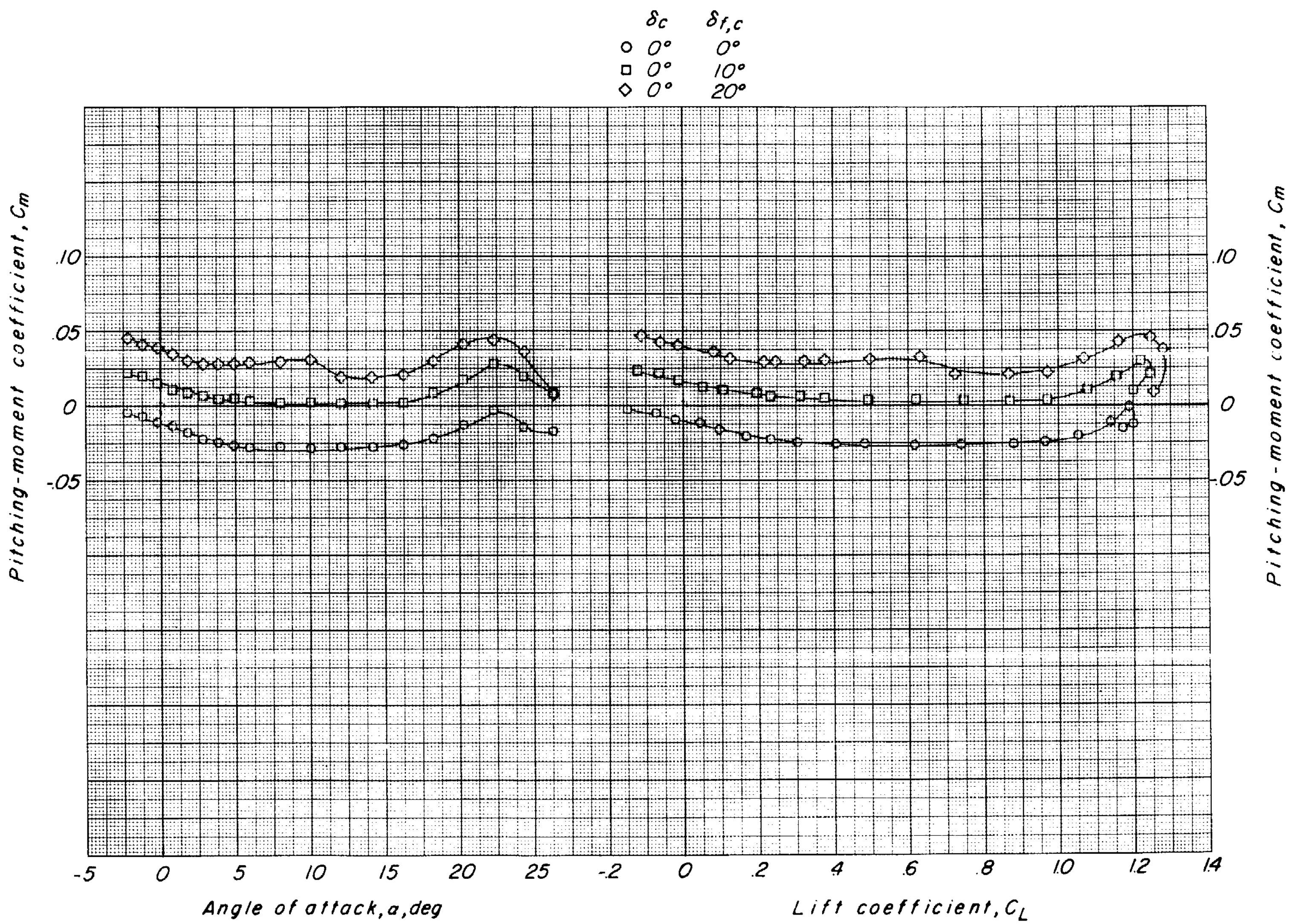


Figure 10.- Concluded.

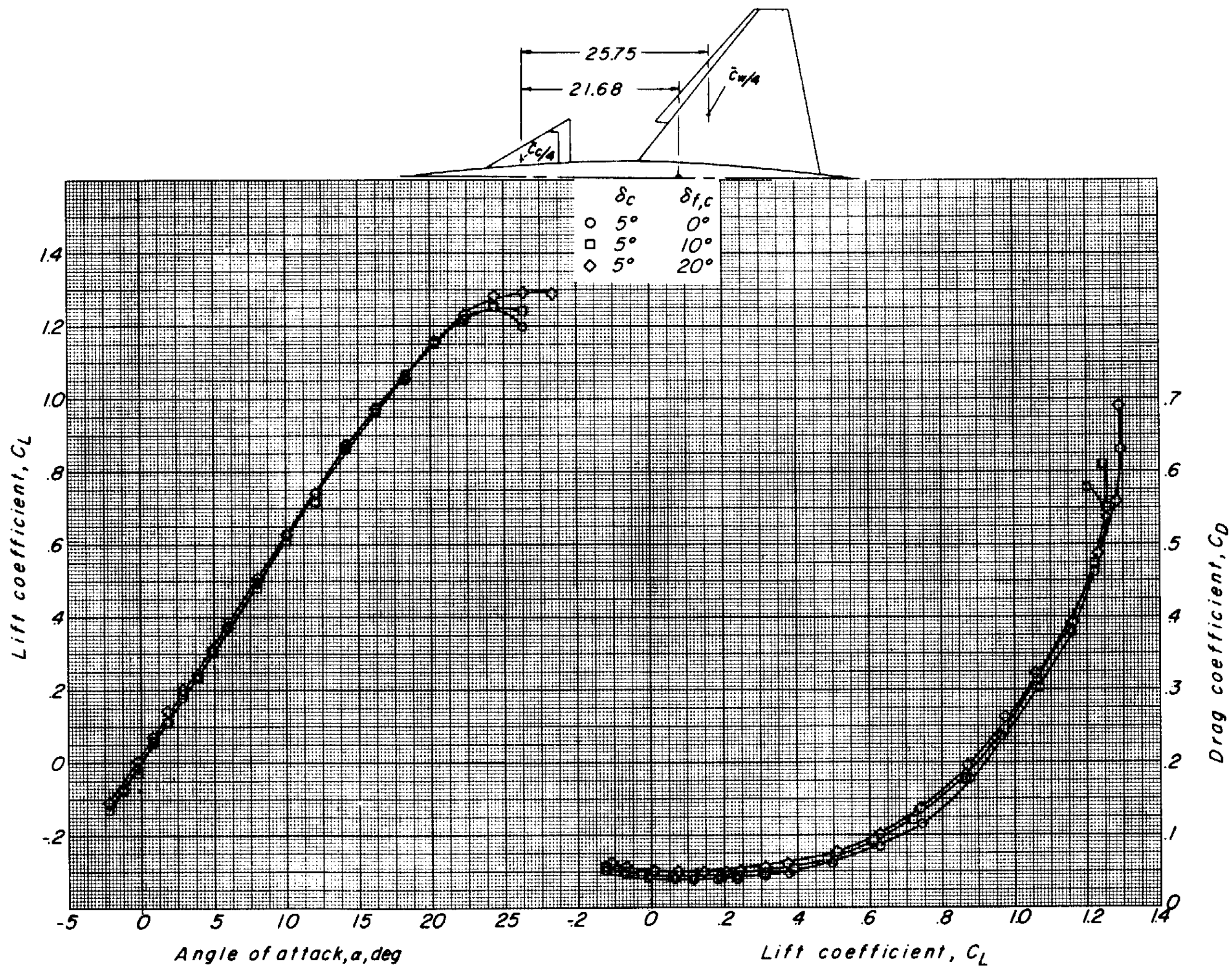


Figure 11.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having delta canard surface at 5° deflection with trailing-edge flap control. $\delta_{n,w} = -30^{\circ}$; $\delta_{f,w} = 0^{\circ}$.

L-1817

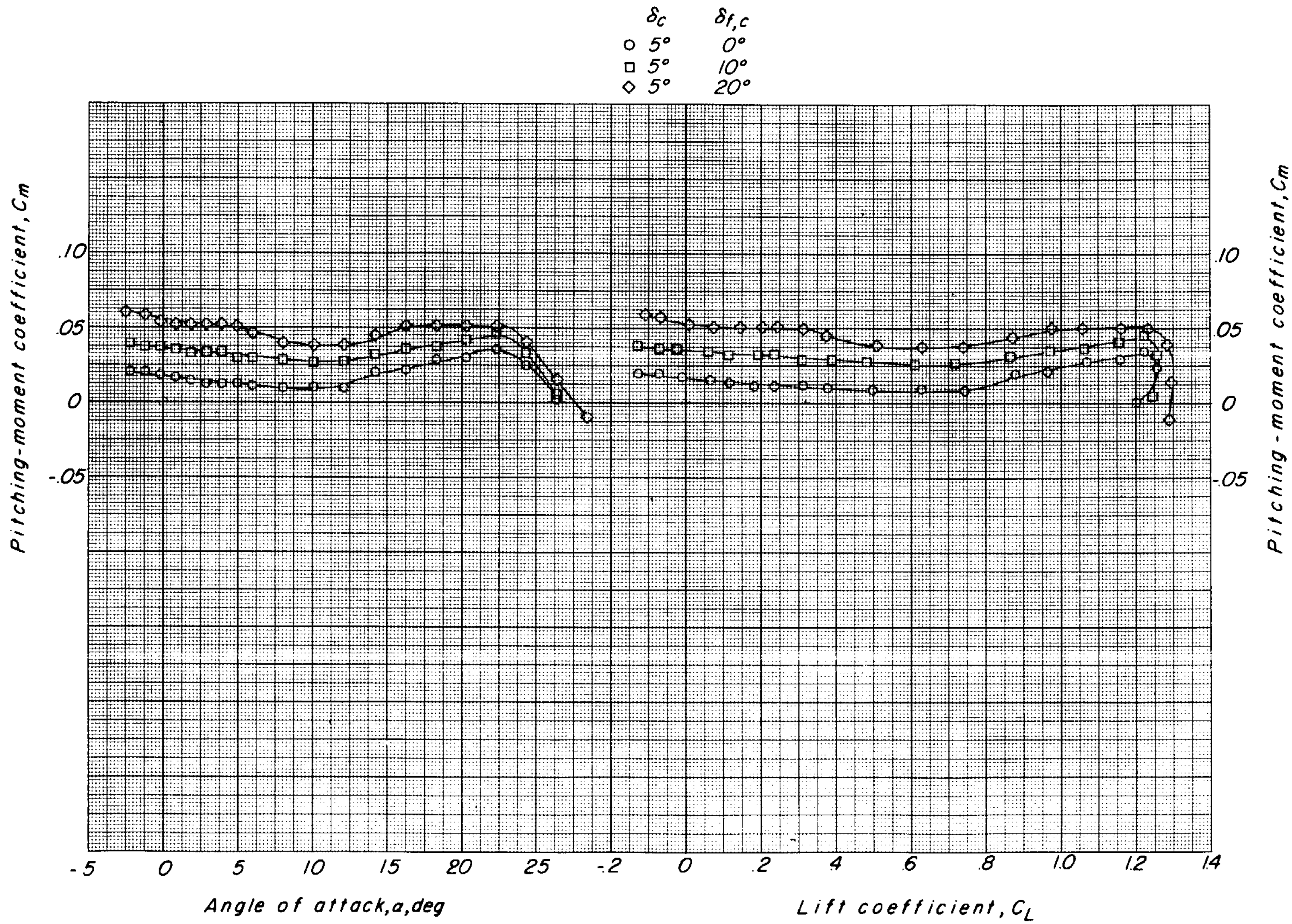


Figure 11.- Concluded.

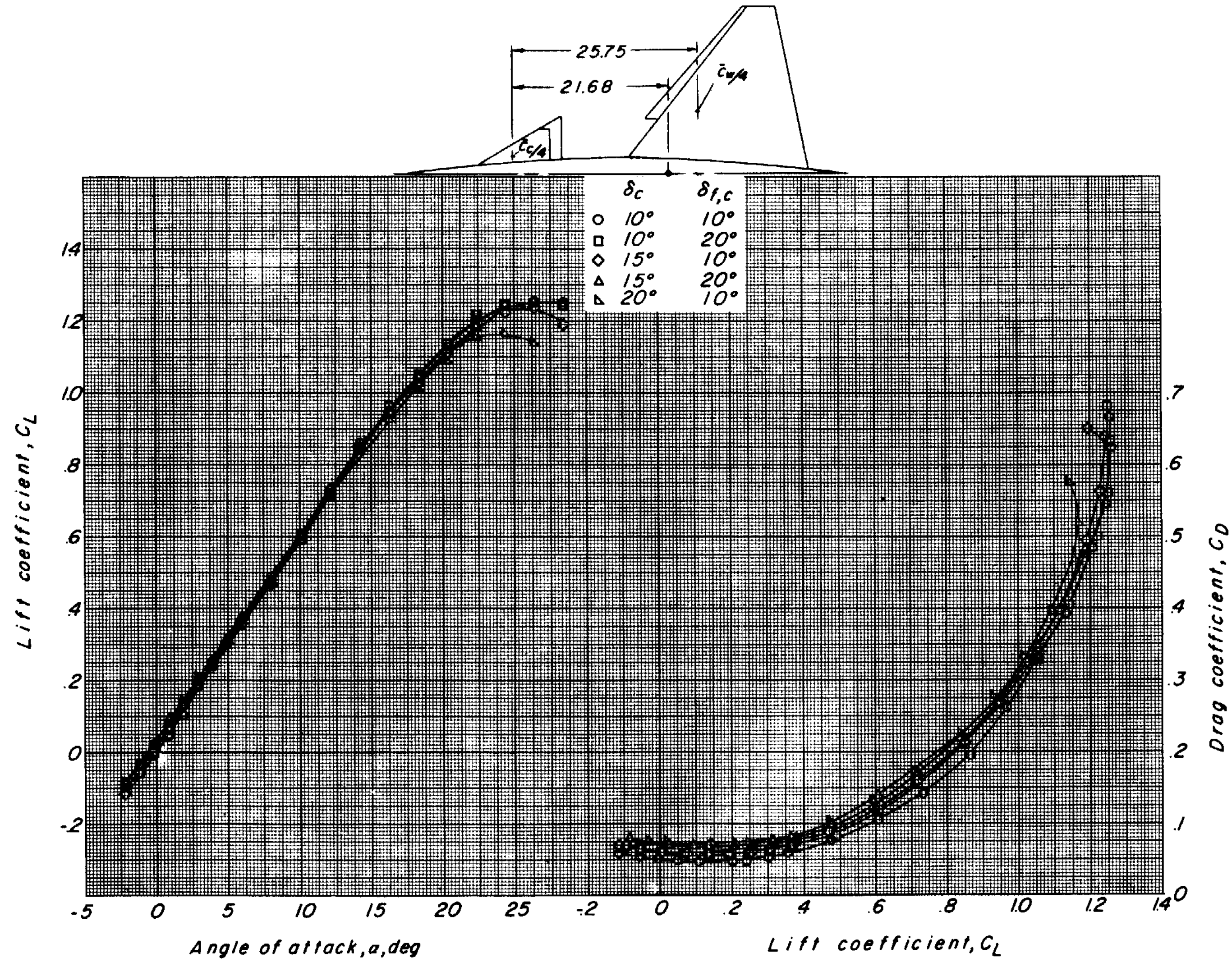


Figure 12.- Longitudinal aerodynamic characteristics of wing having leading-edge chord-extension and having delta canard with trailing-edge flap control. $\delta_{n,w} = -30^{\circ}$; $\delta_{f,w} = 0^{\circ}$.

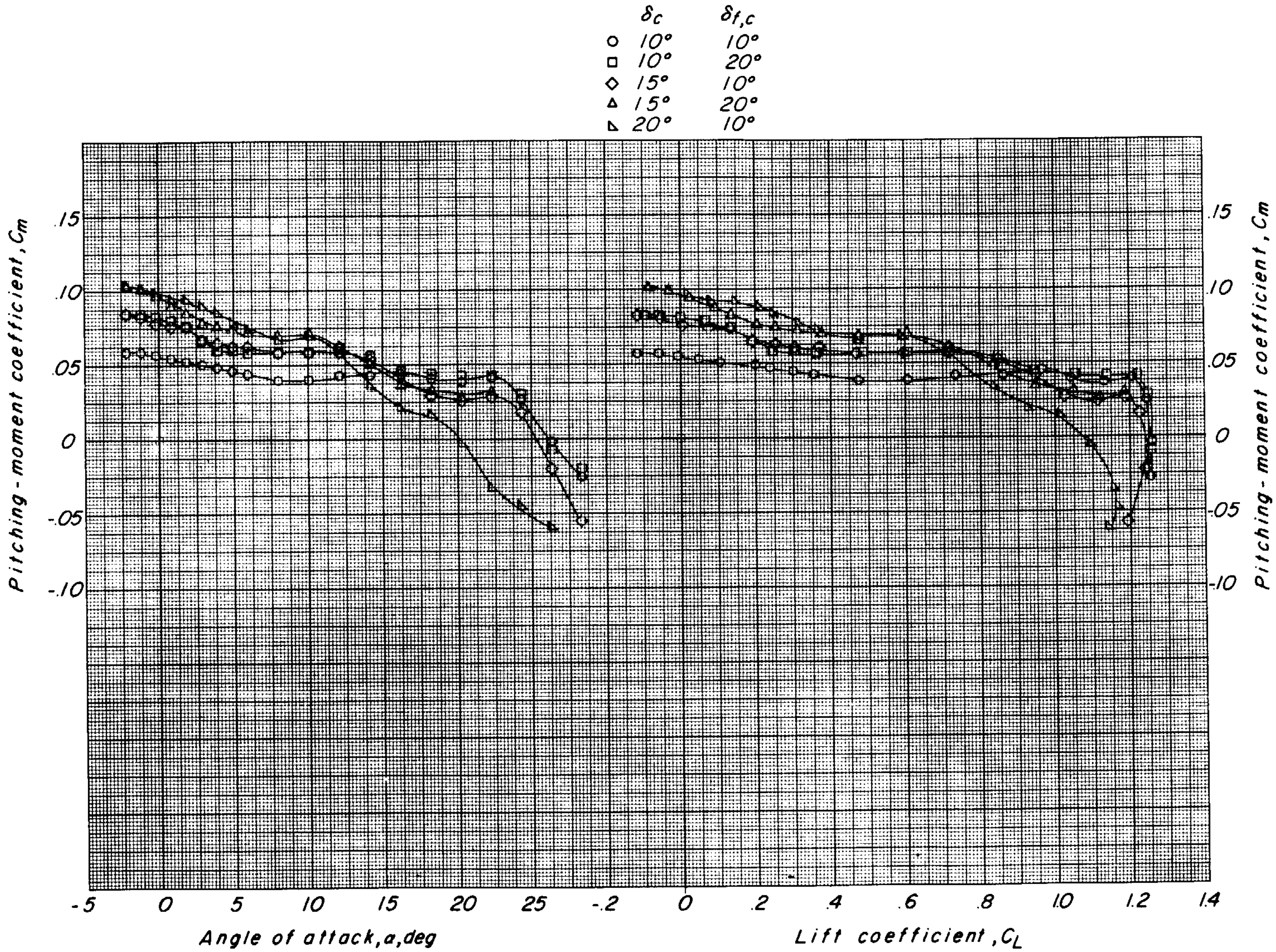


Figure 12.- Concluded.

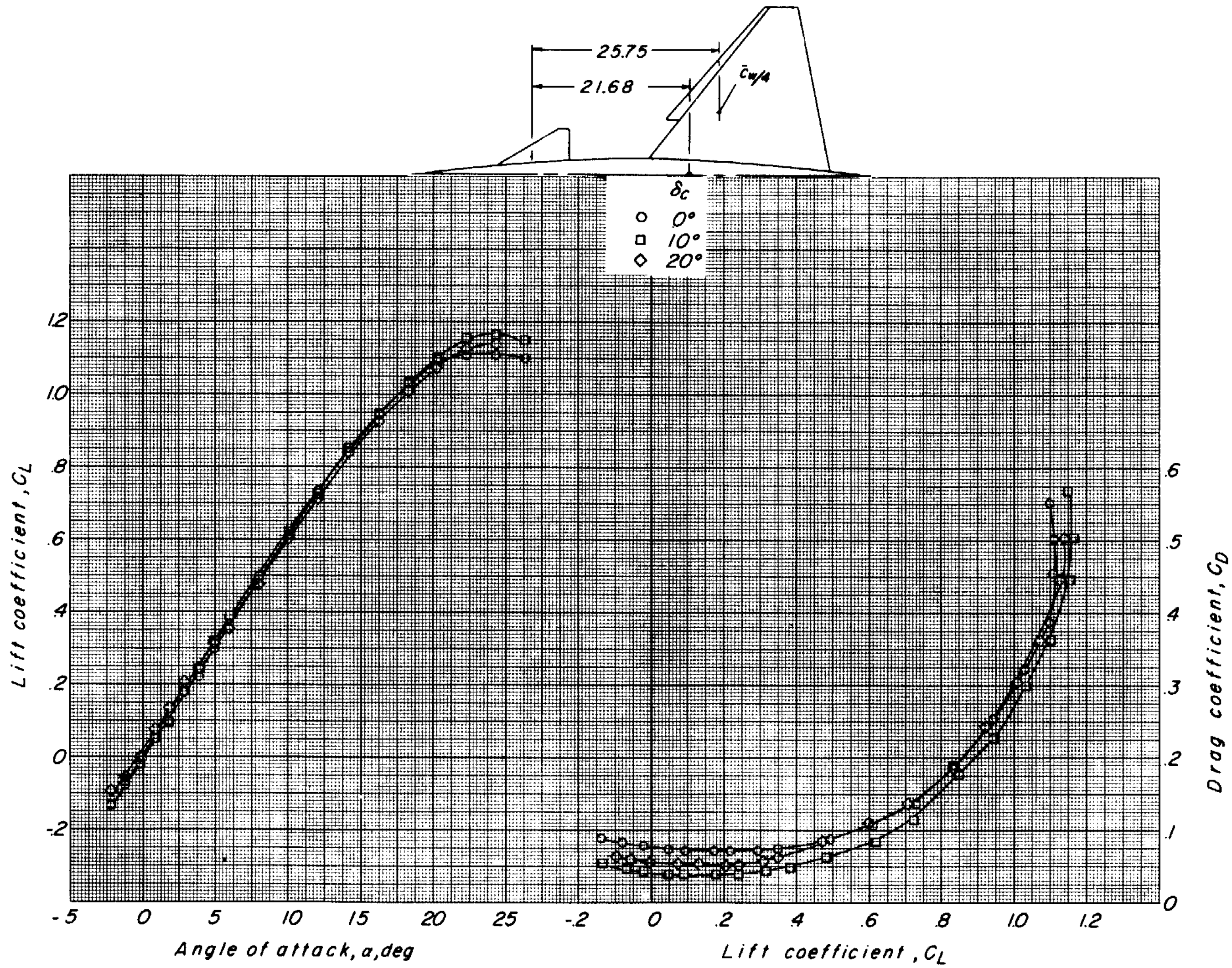


Figure 13.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having modified 60° delta canard surface. $\delta_{n,w} = -30^\circ$; $\delta_{f,w} = 0^\circ$.

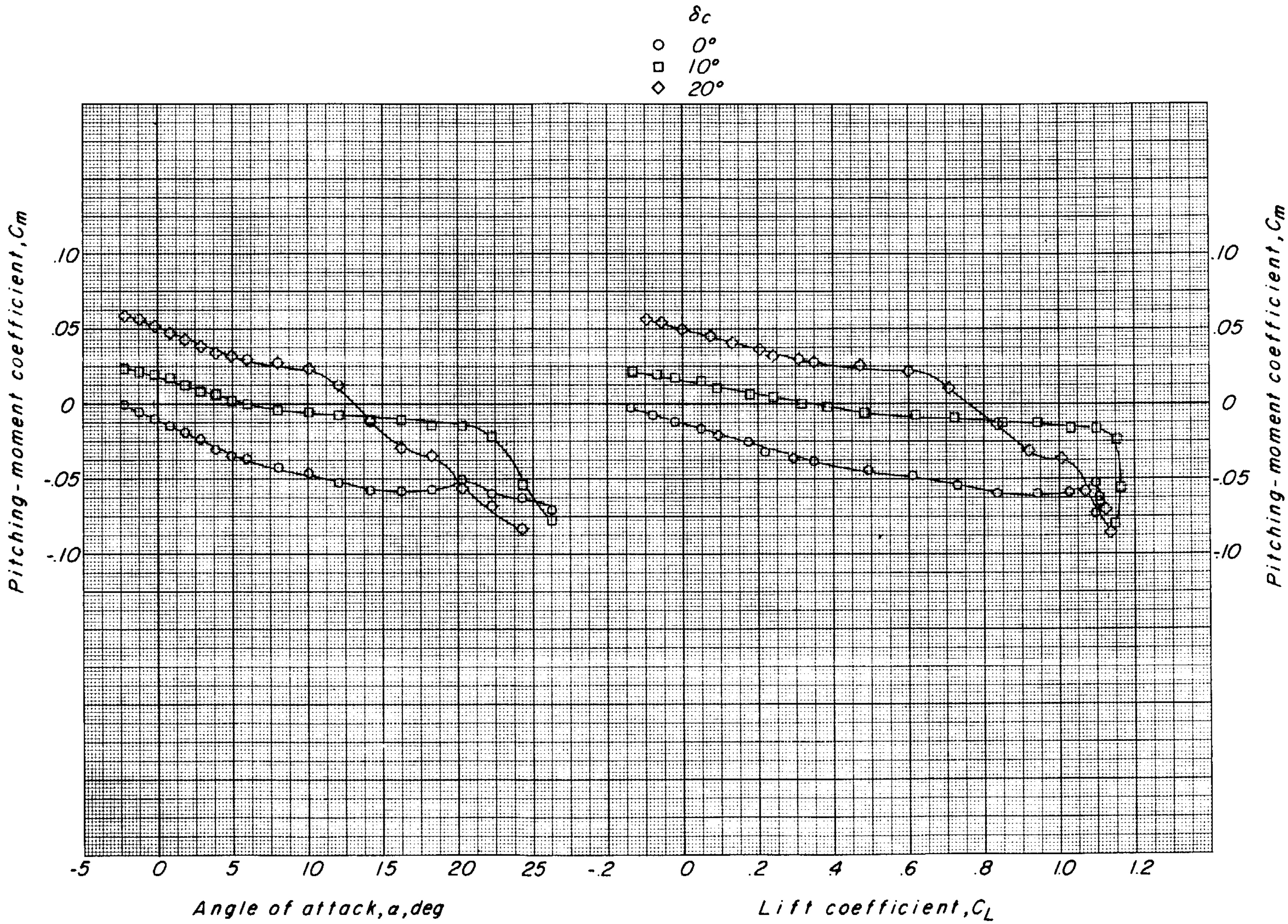
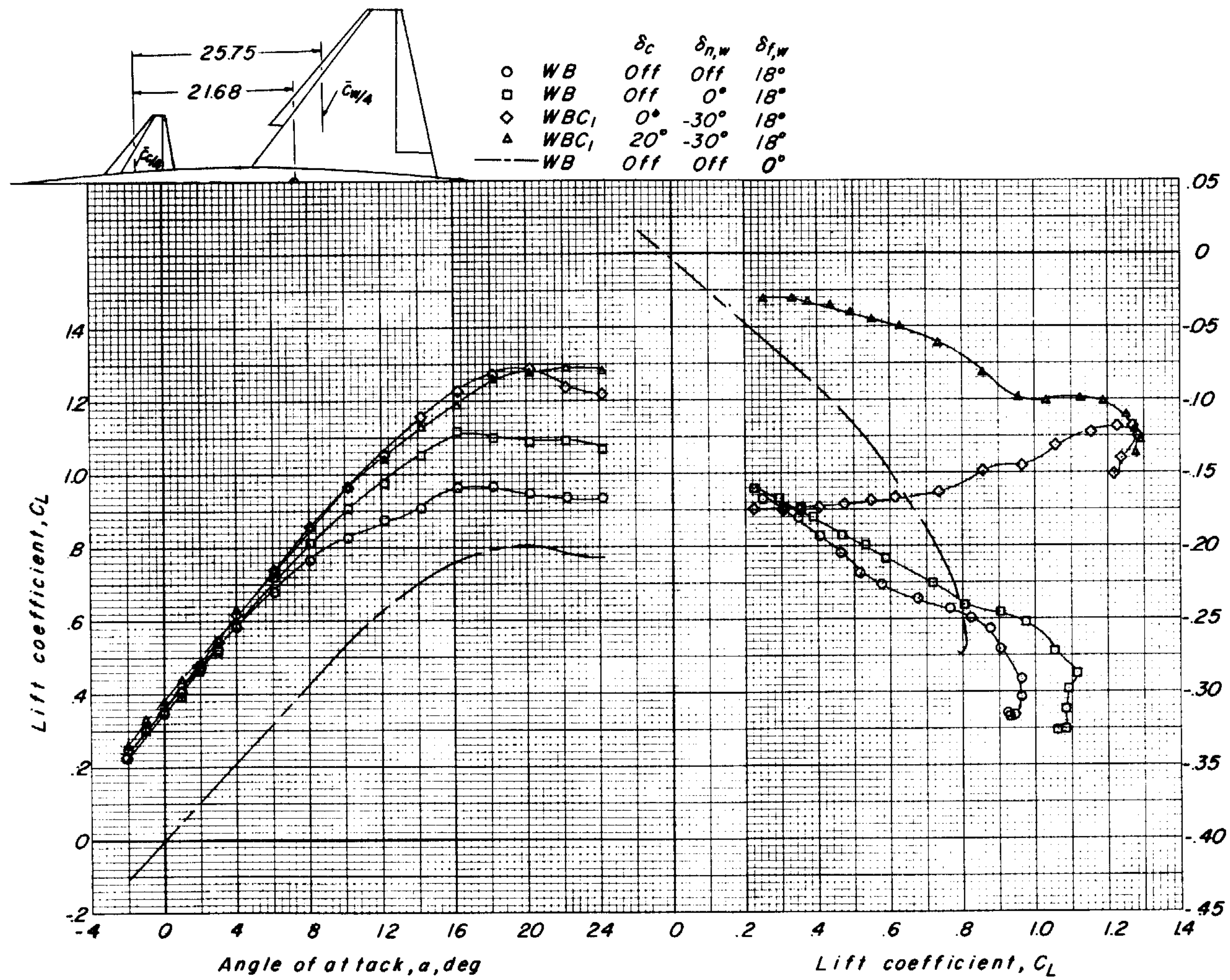
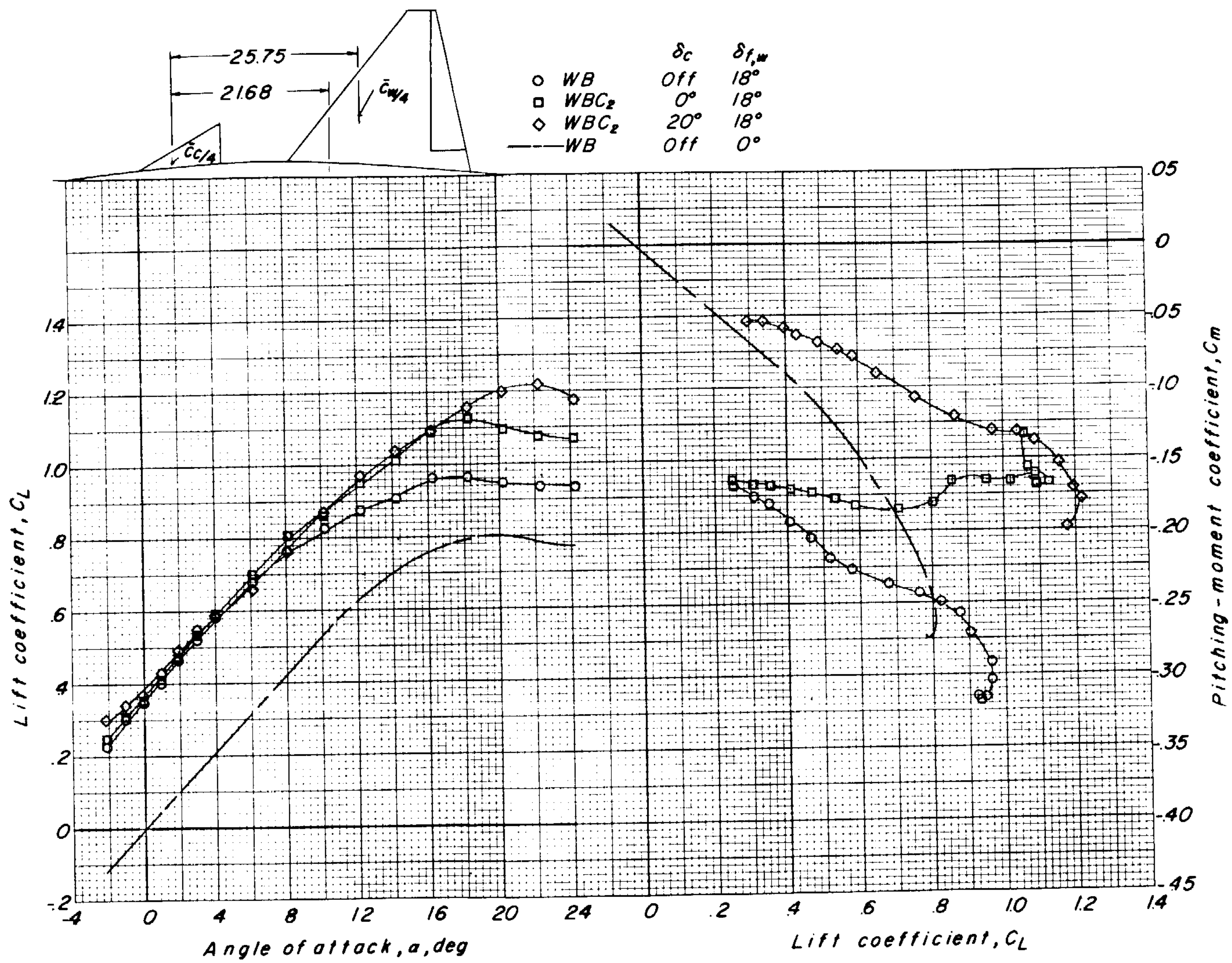


Figure 13.- Concluded.



(a) Trapezoidal canard surface.

Figure 14.- Canard effectiveness in producing trim for configuration with wing trailing-edge flaps deflected.



(b) Basic wing and delta canard surface.

Figure 14.- Concluded.

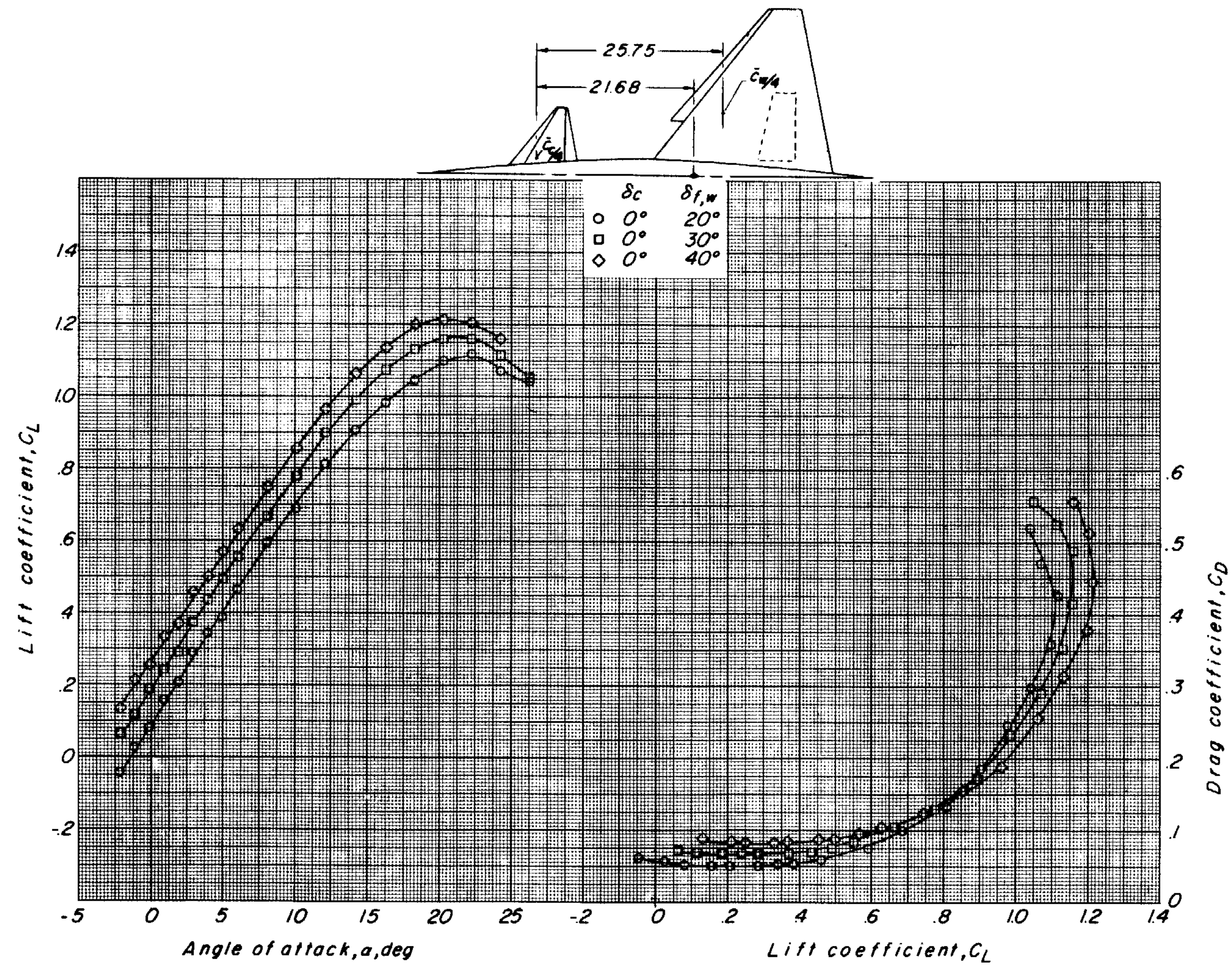


Figure 15.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and with split flaps located between $0.60c_w$ and $0.80c_w$ and having trapezoidal canard surface with all controls at 0° deflection. $\delta_{n,w} = -30^{\circ}$.

L-1817

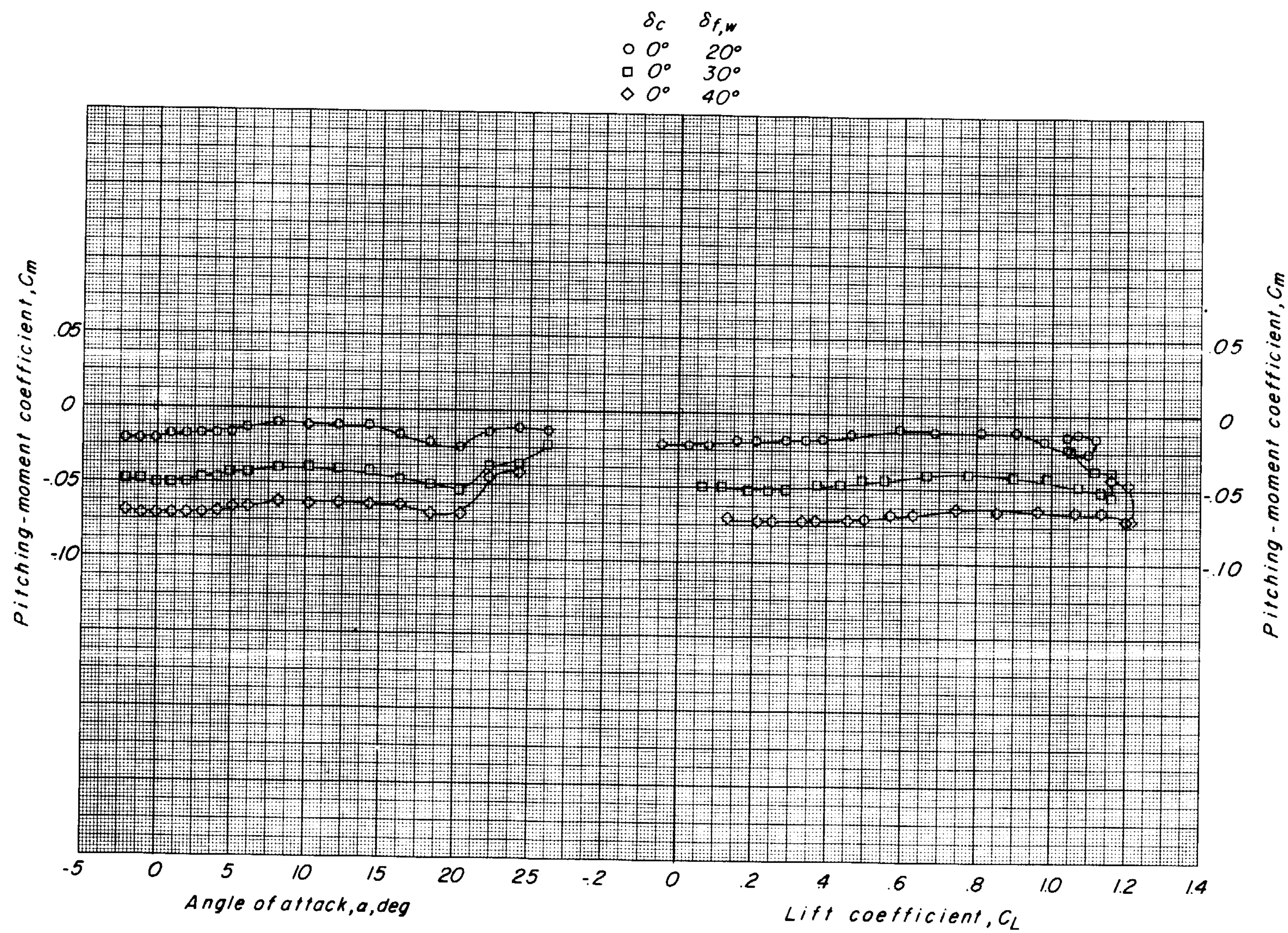


Figure 15.- Concluded.

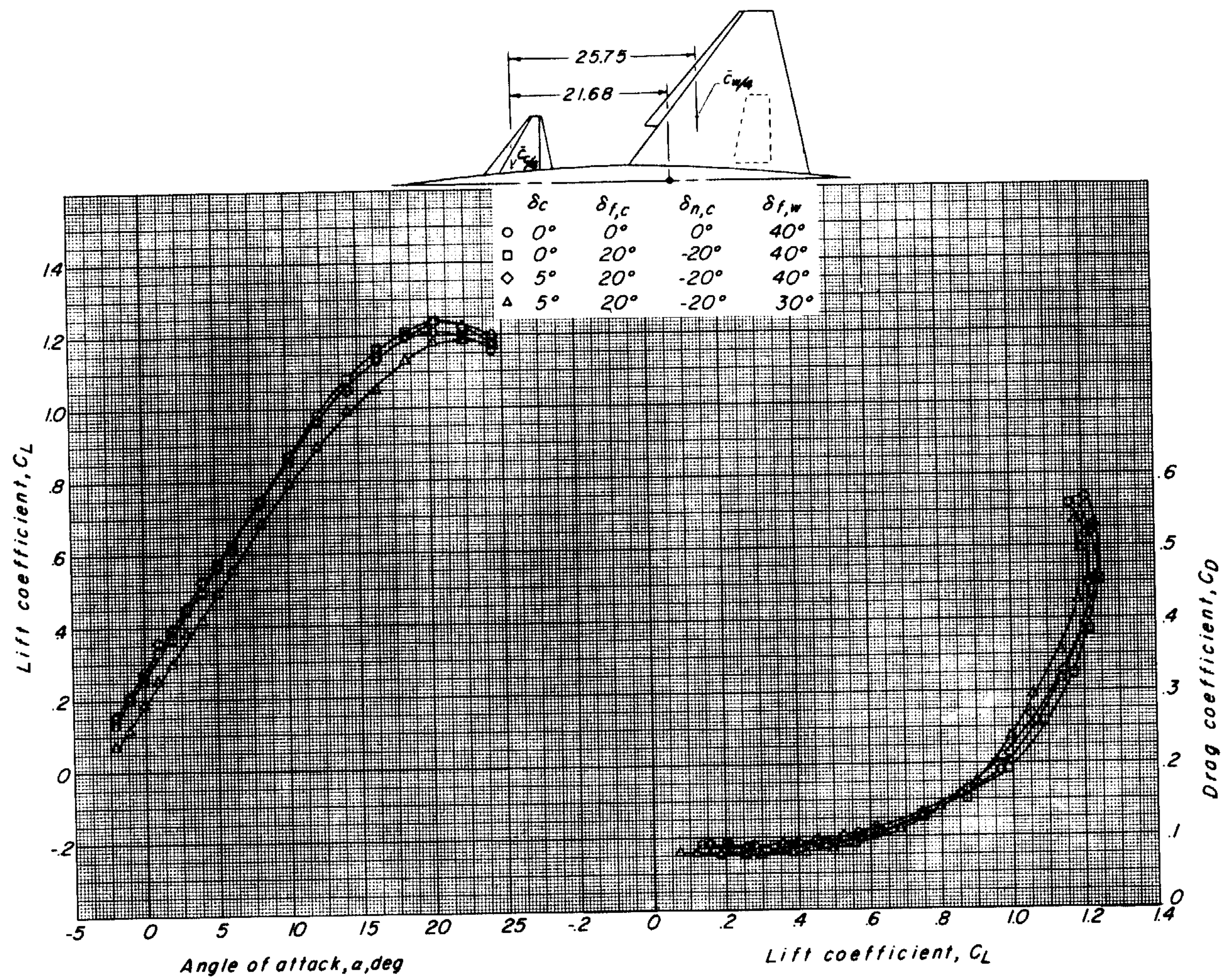


Figure 16.- Longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and with split flaps located between $0.60c_w$ and $0.80c_w$ and having trapezoidal canard surface at various deflections. $\delta_{n,w} = -30^{\circ}$.

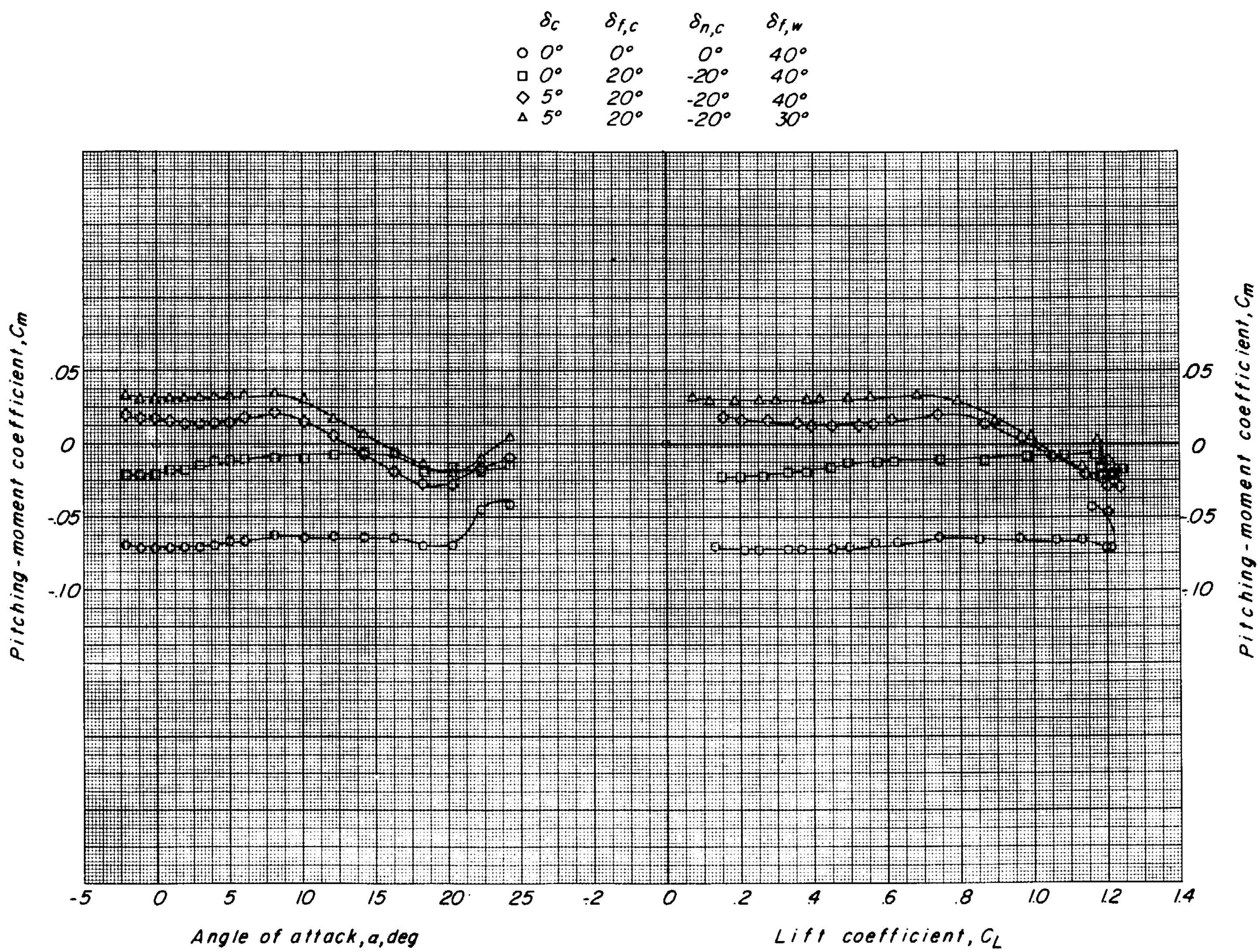


Figure 16.- Concluded.

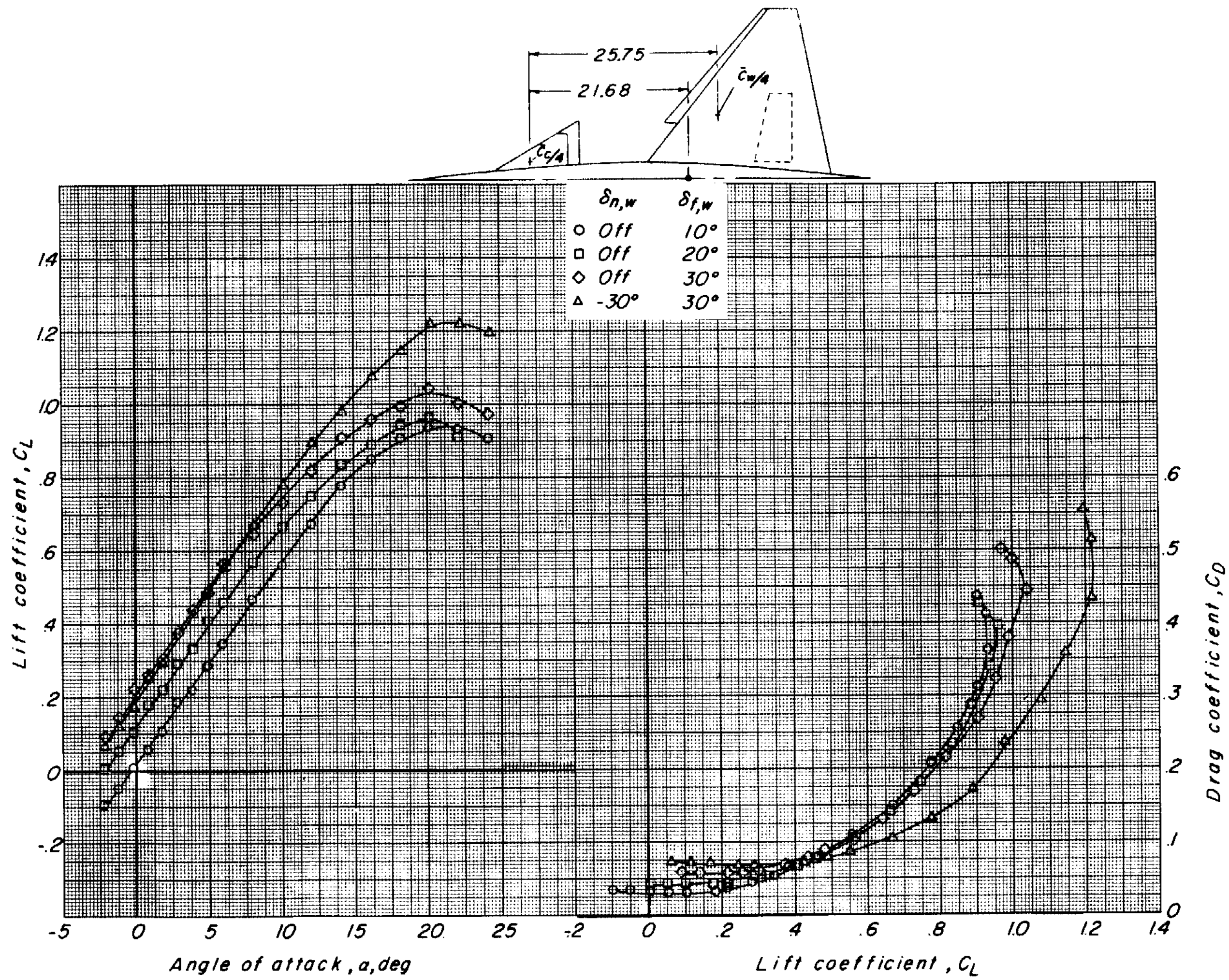


Figure 17.- Longitudinal aerodynamic characteristics of configuration having wing with split flaps located between $0.60c_w$ and $0.80c_w$ and having delta canard surface. $\delta_c = 0^\circ$; $\delta_{f,c} = 0^\circ$.

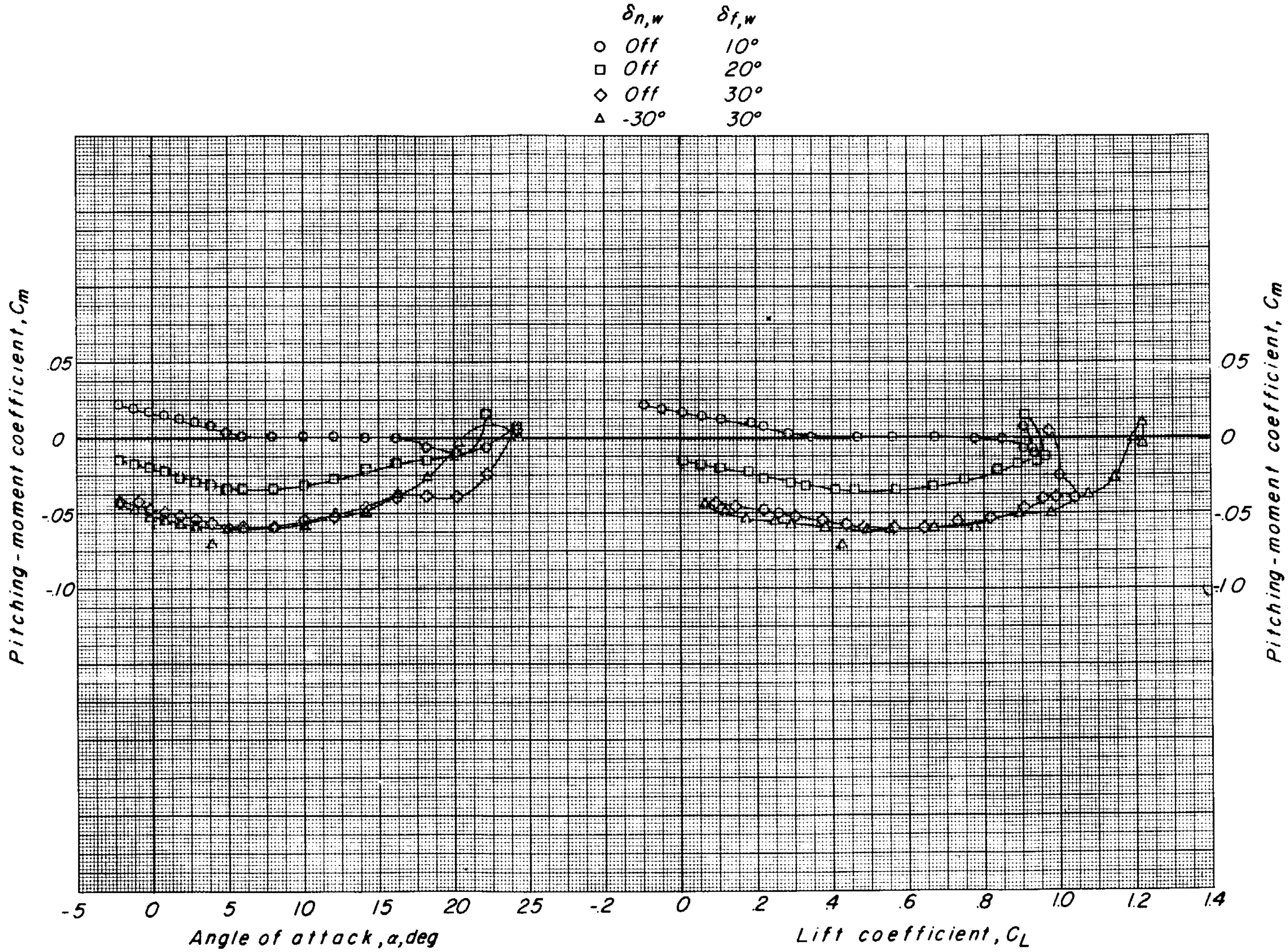


Figure 17.- Concluded.

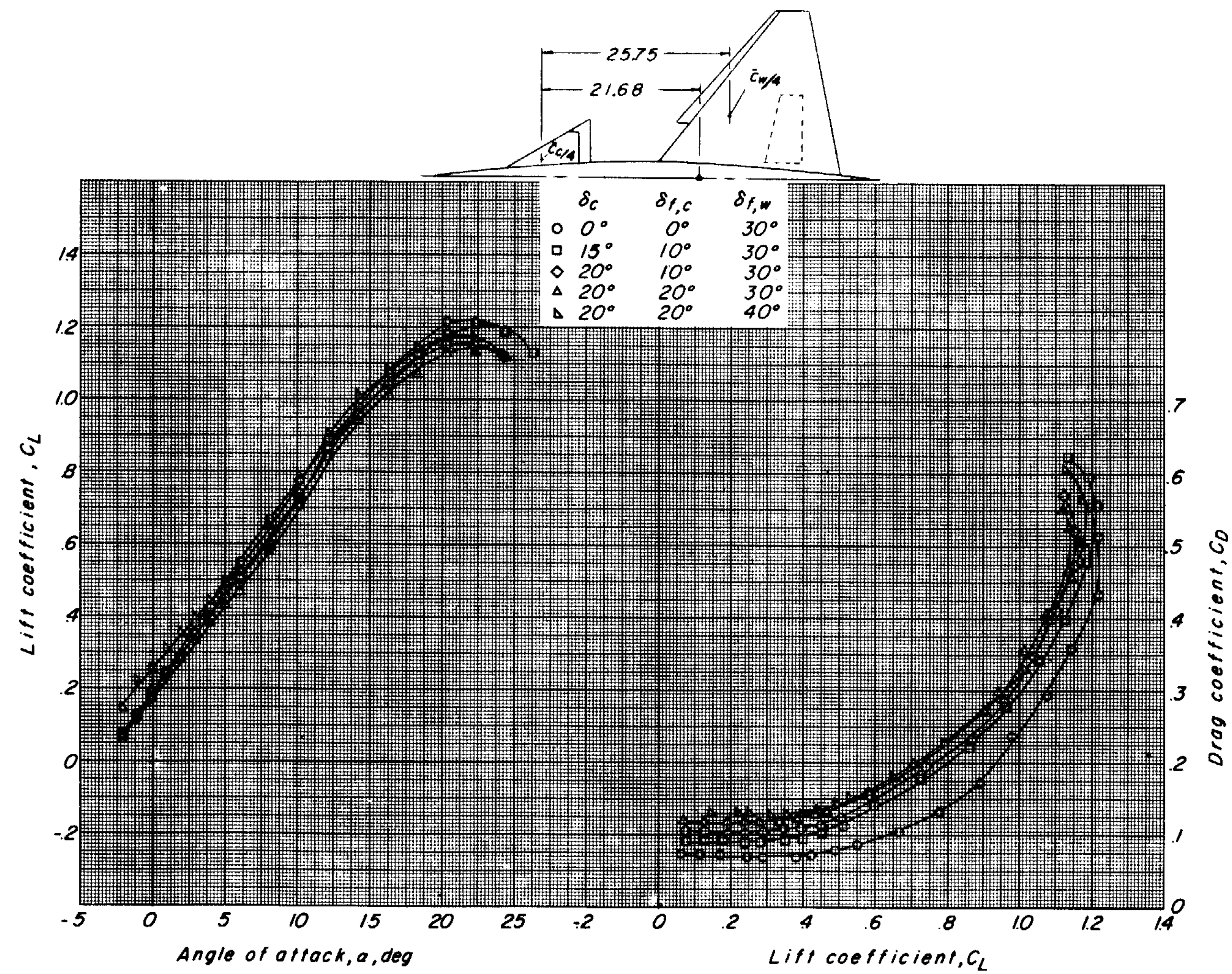


Figure 18.- Longitudinal aerodynamic characteristics of configuration having wing with split flaps located between $0.60c_w$ and $0.80c_w$ and having delta canard surface with leading-edge chord-extension. $\delta_{n,w} = -30^\circ$.

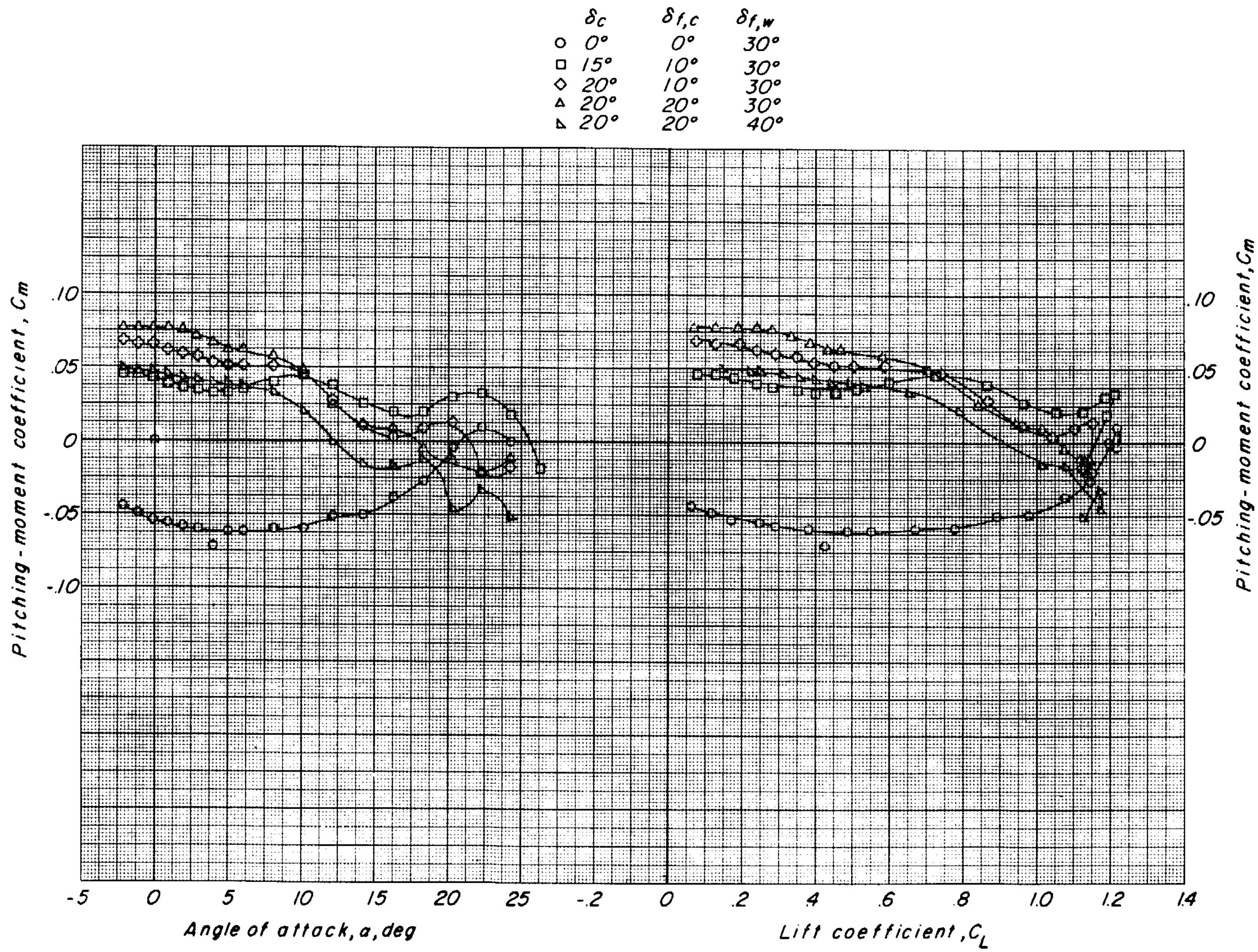


Figure 18.- Concluded.

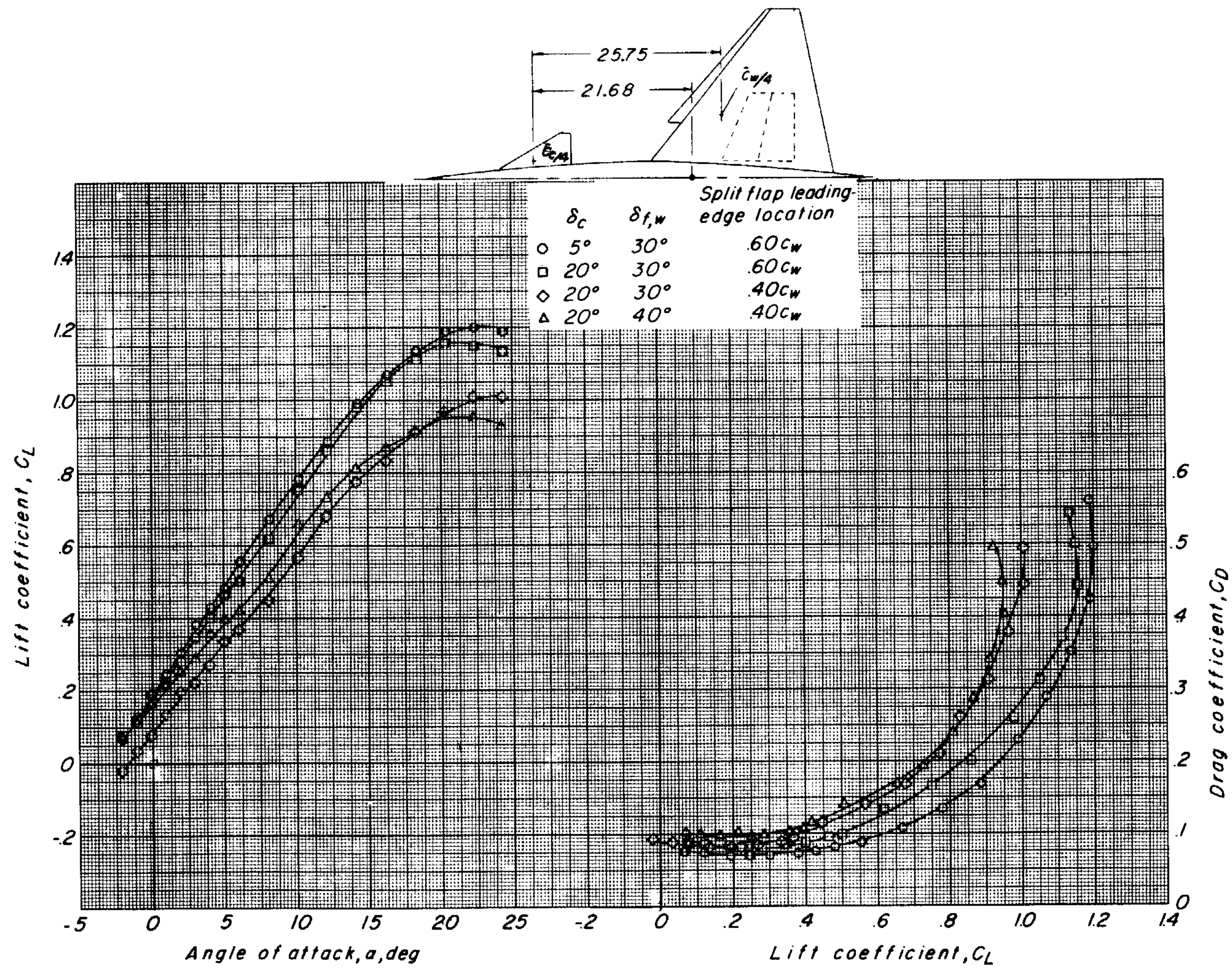


Figure 19.- Effect of wing flap location on longitudinal aerodynamic characteristics of configuration having wing with leading-edge chord-extension and having modified delta canard surface. $\delta_{n,w} = -30^{\circ}$.

L-1817

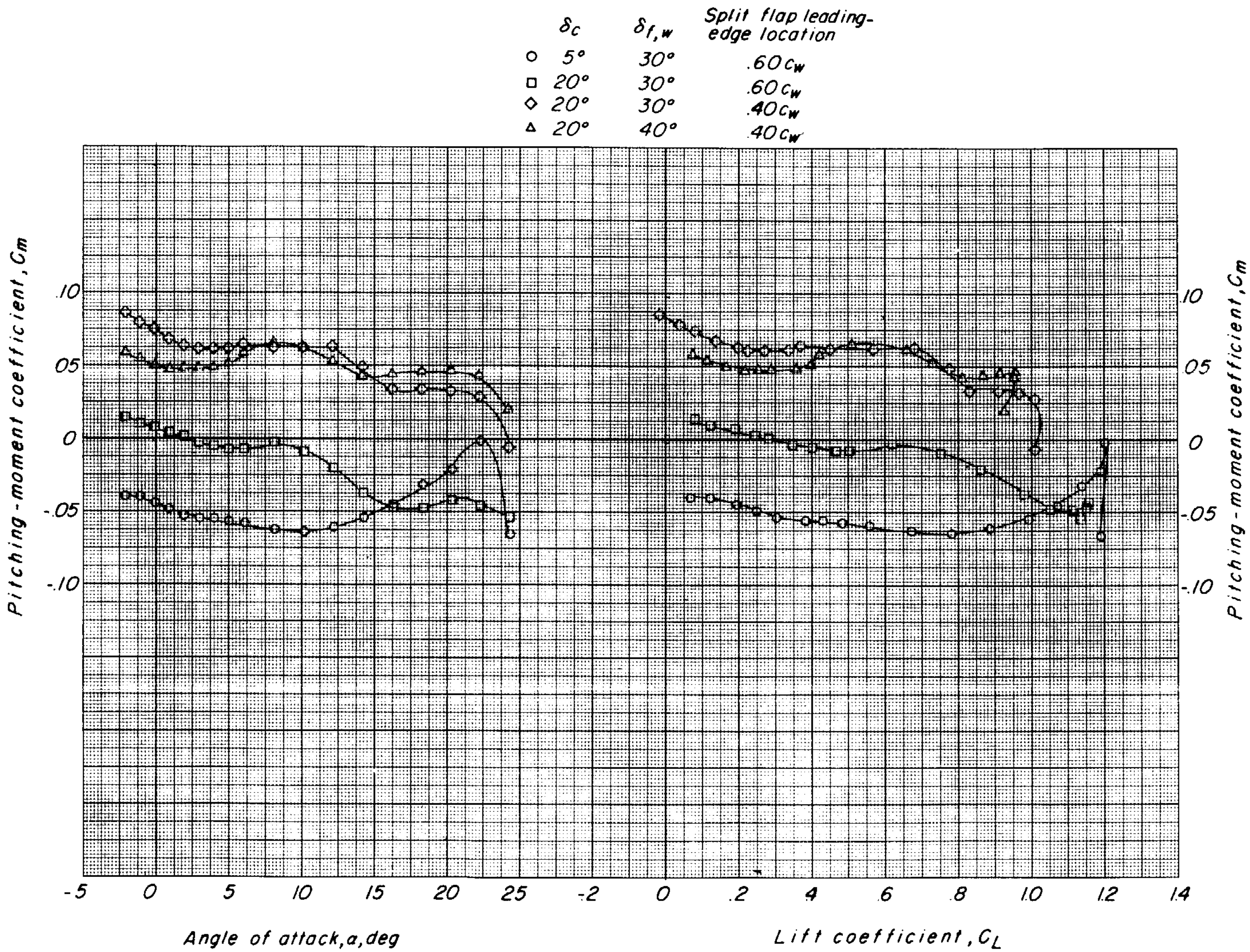
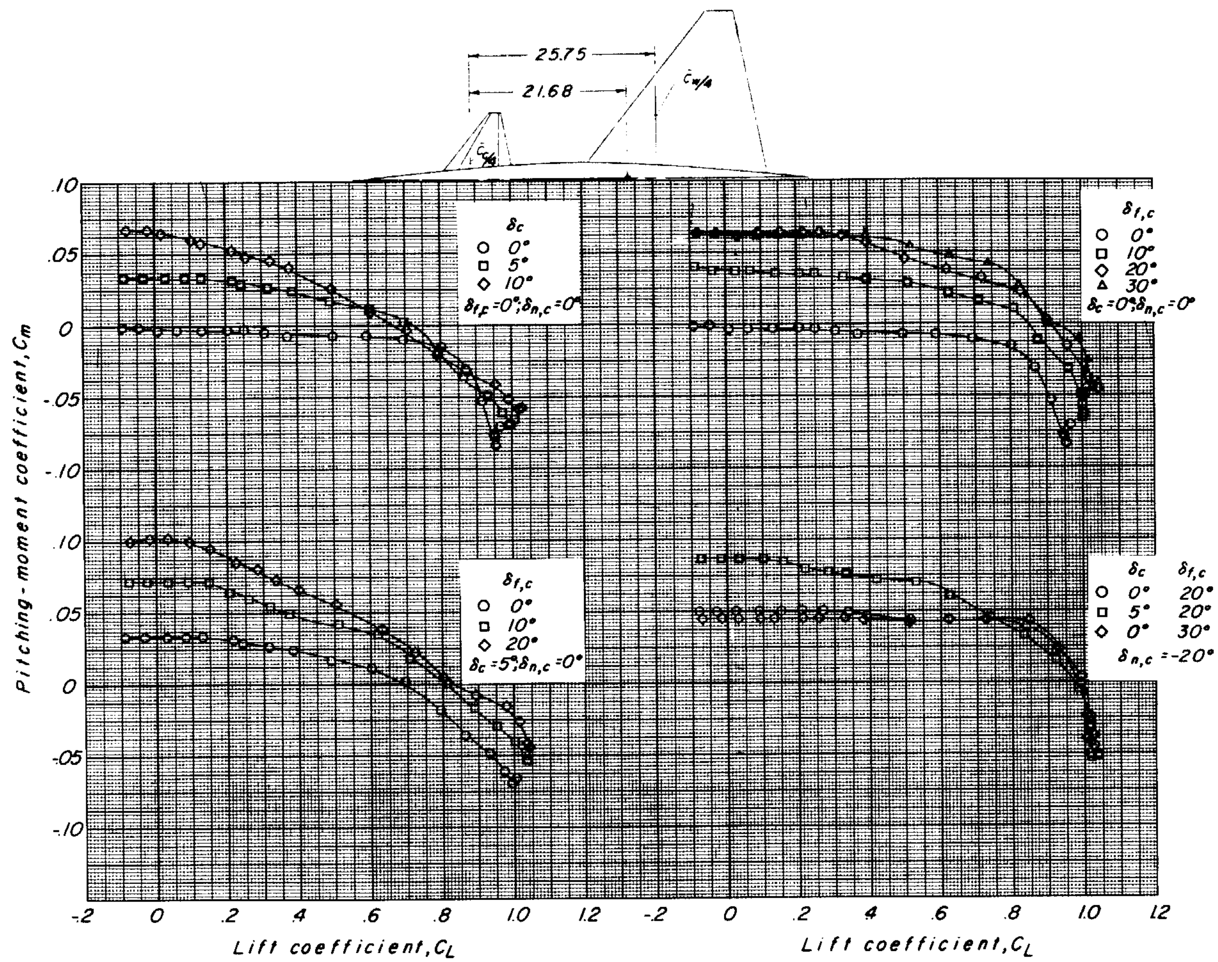
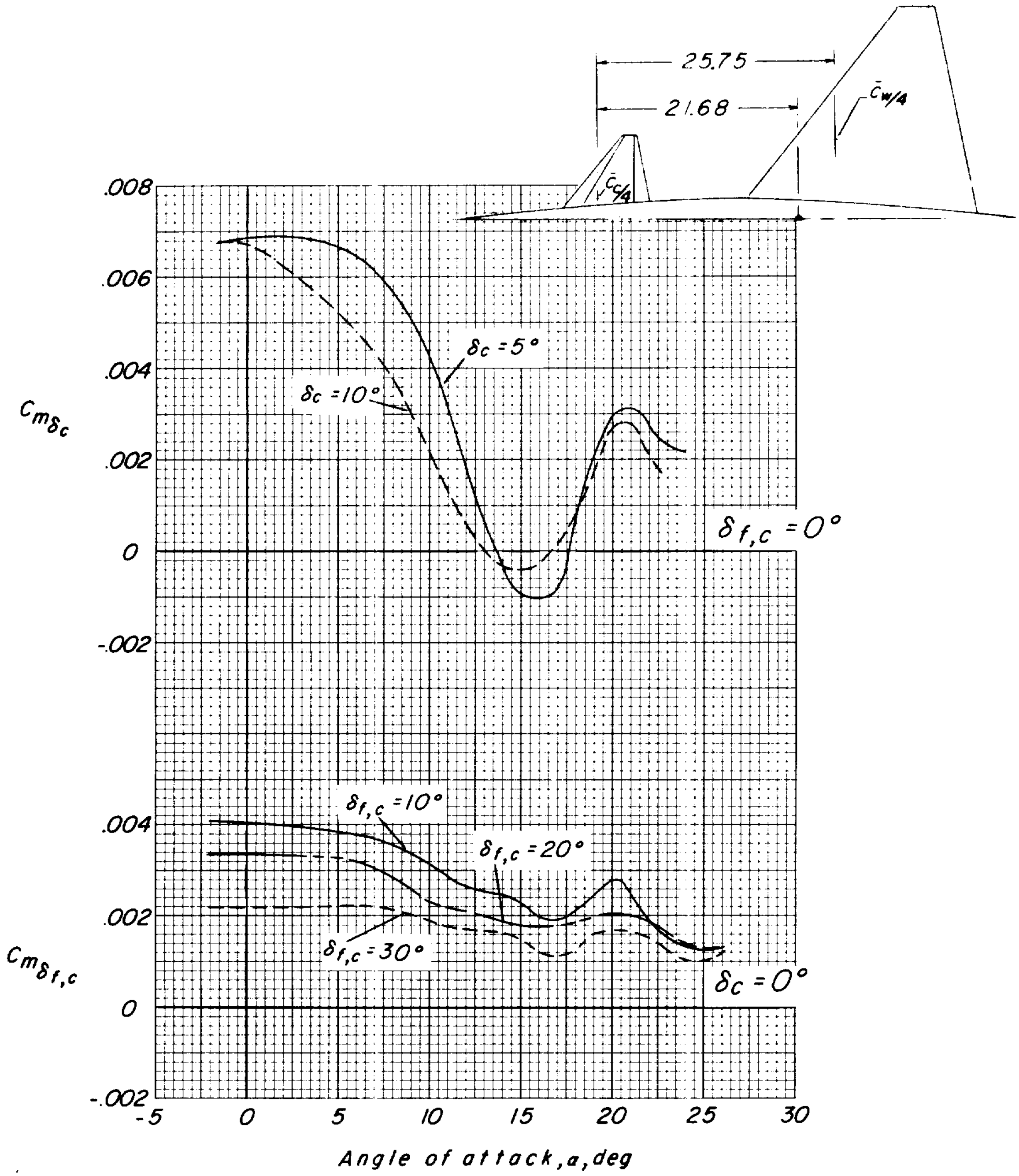


Figure 19.- Concluded.



(a) Variation of pitching-moment coefficient with lift coefficient.

Figure 20.- Longitudinal stability and control characteristics of basic-wing—trapezoidal-canard configuration associated with deflection of canard surface and leading- and trailing-edge flaps of canard surface. $\delta_{f,w} = 0^{\circ}$; $\delta_{n,w}$ = Off.



(b) Variation of control effectiveness parameter with angle of attack.

Figure 20.- Concluded.

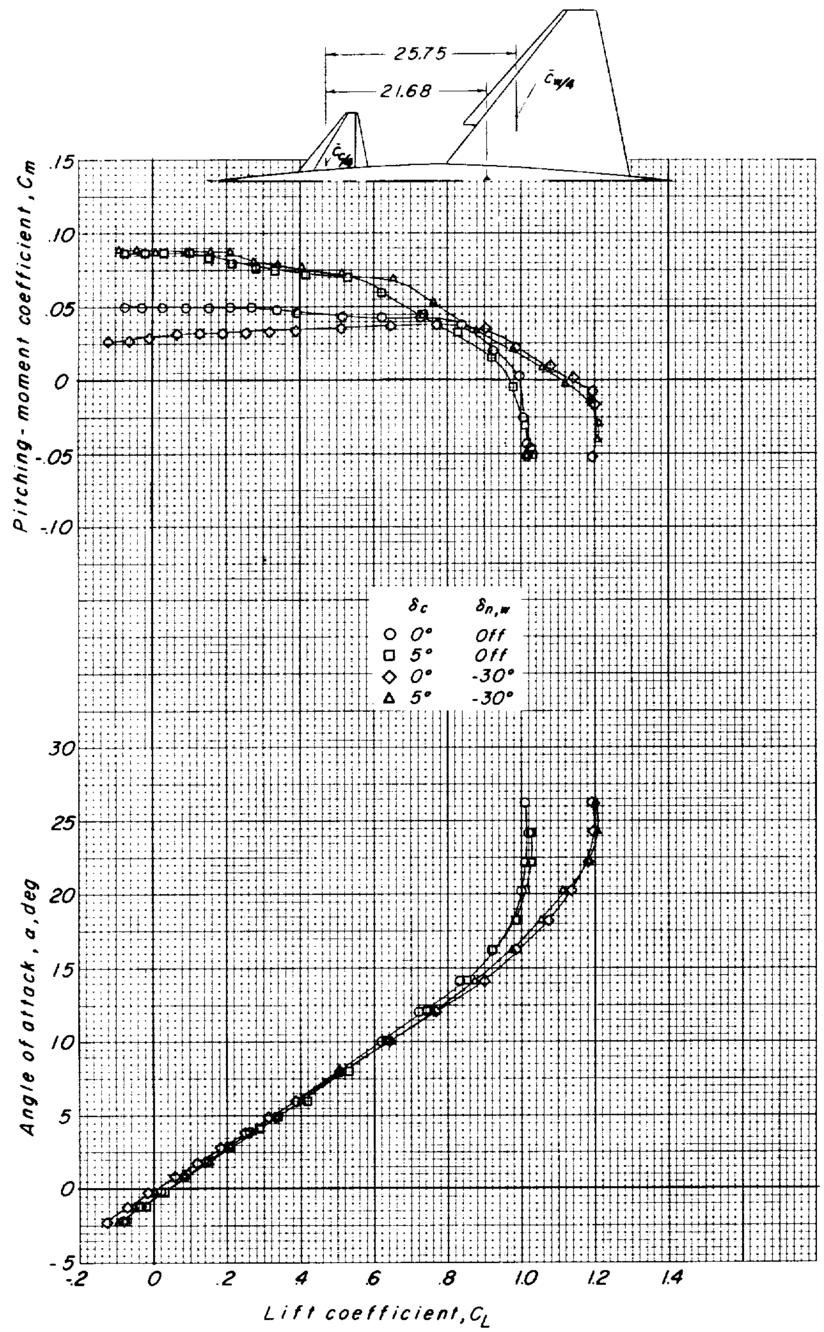


Figure 21.- Effects of addition and deflection of wing leading-edge chord-extension on lift and longitudinal stability characteristics associated with configuration having trapezoidal canard control. $\delta_{f,c} = 20^{\circ}$; $\delta_{n,c} = -20^{\circ}$.

L-1817

L-1817

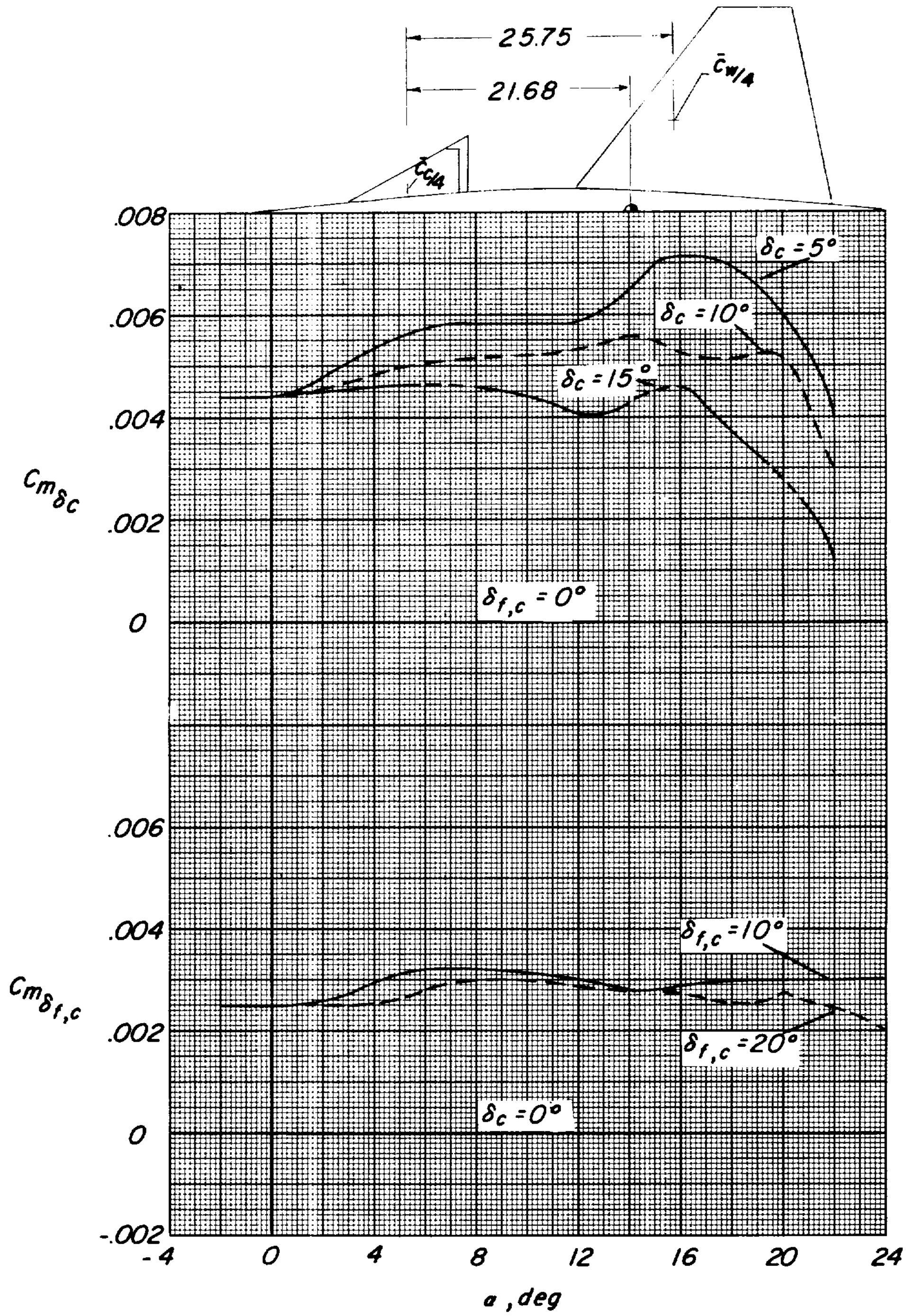


Figure 22.- Comparison of longitudinal control characteristics associated with deflection of delta canard and trailing-edge flap of delta canard. $\delta_{n,w} = -30^{\circ}$; $\delta_{f,w} = 0^{\circ}$.

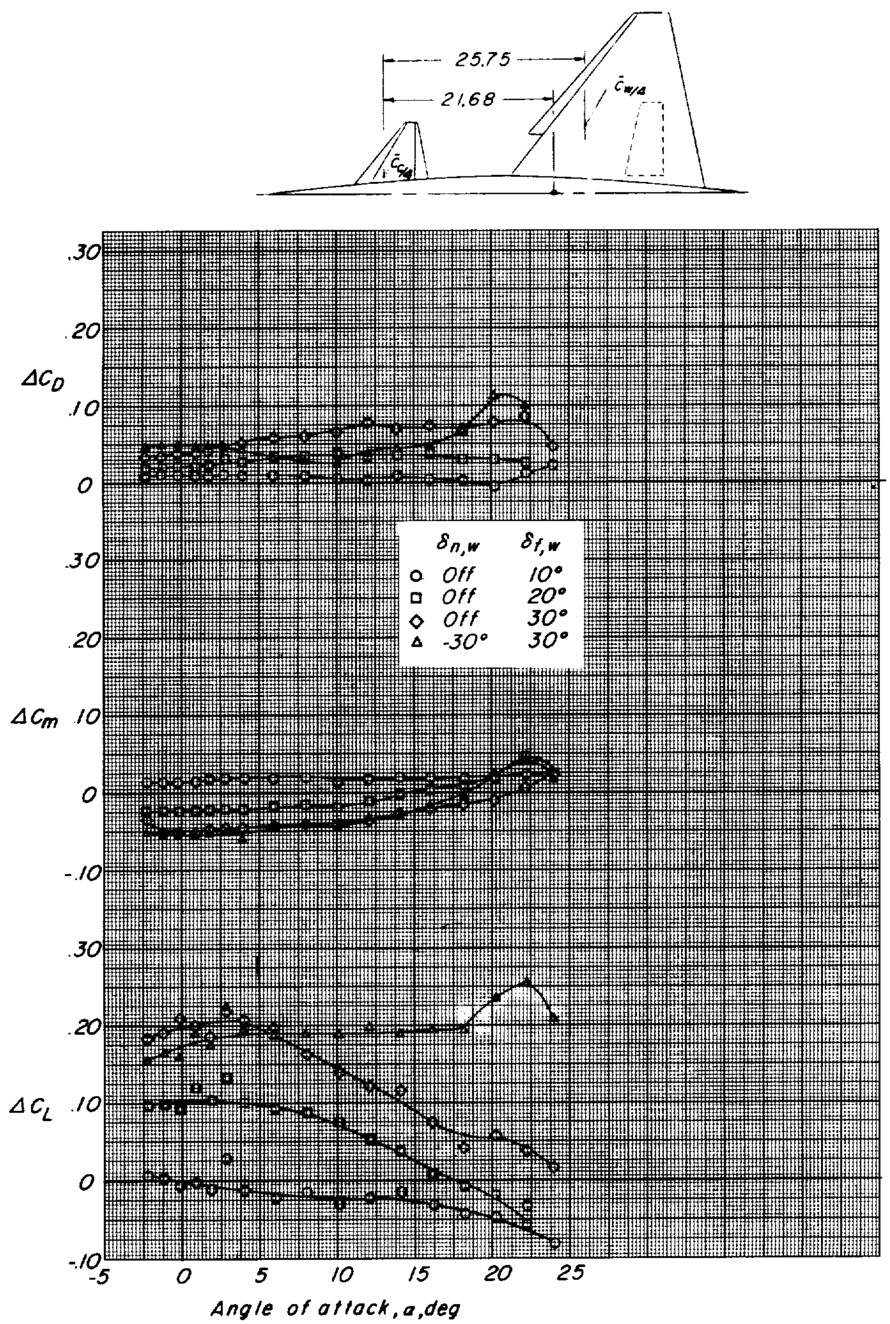


Figure 23.- Incremental effects of deflection of wing split flaps on longitudinal aerodynamic characteristics of configuration having wing with split flaps located between $0.60c_w$ and $0.80c_w$ and having trapezoidal canard surface with all control deflections at 0°.

L-1817